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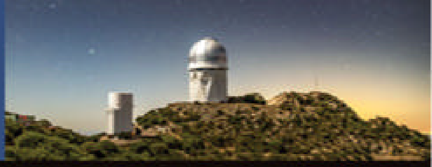

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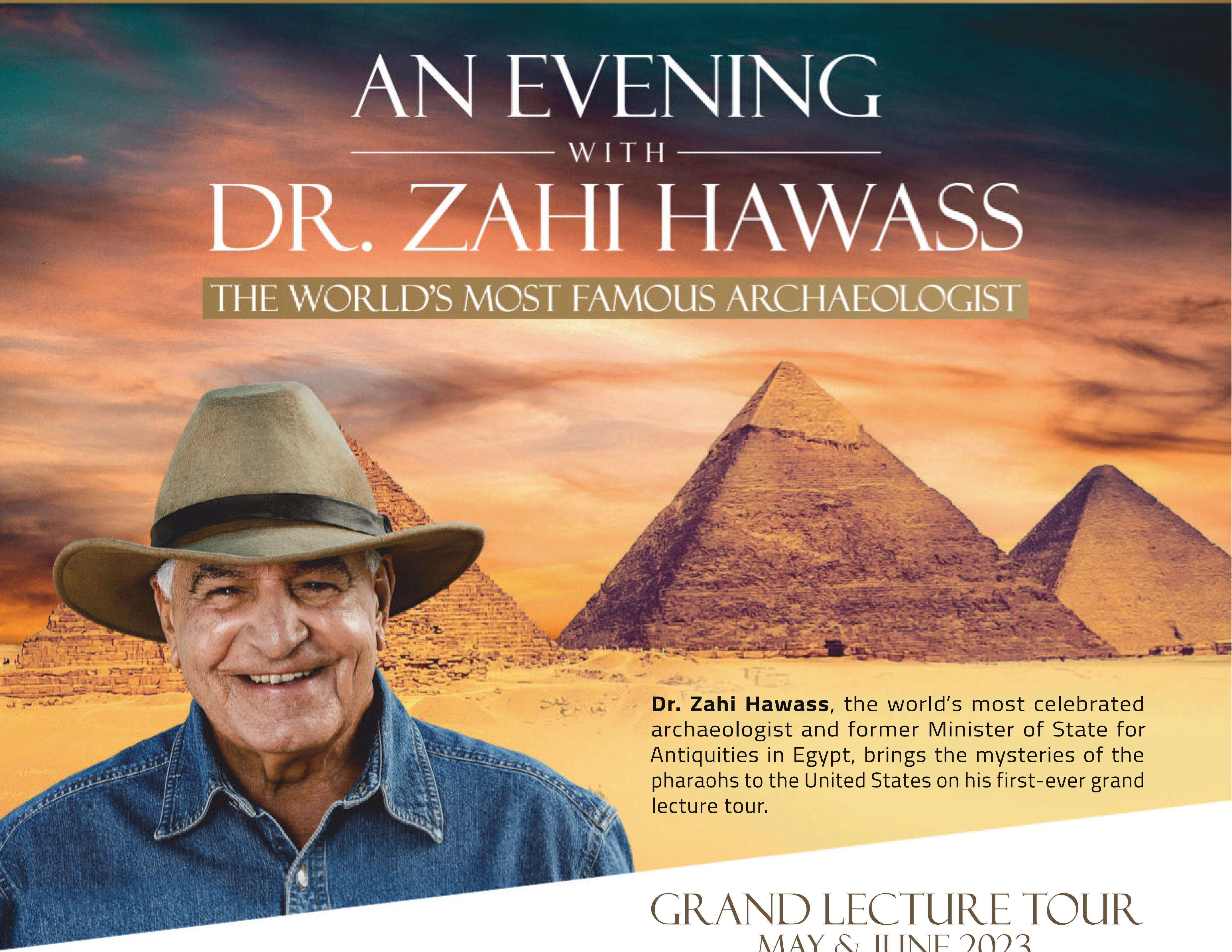

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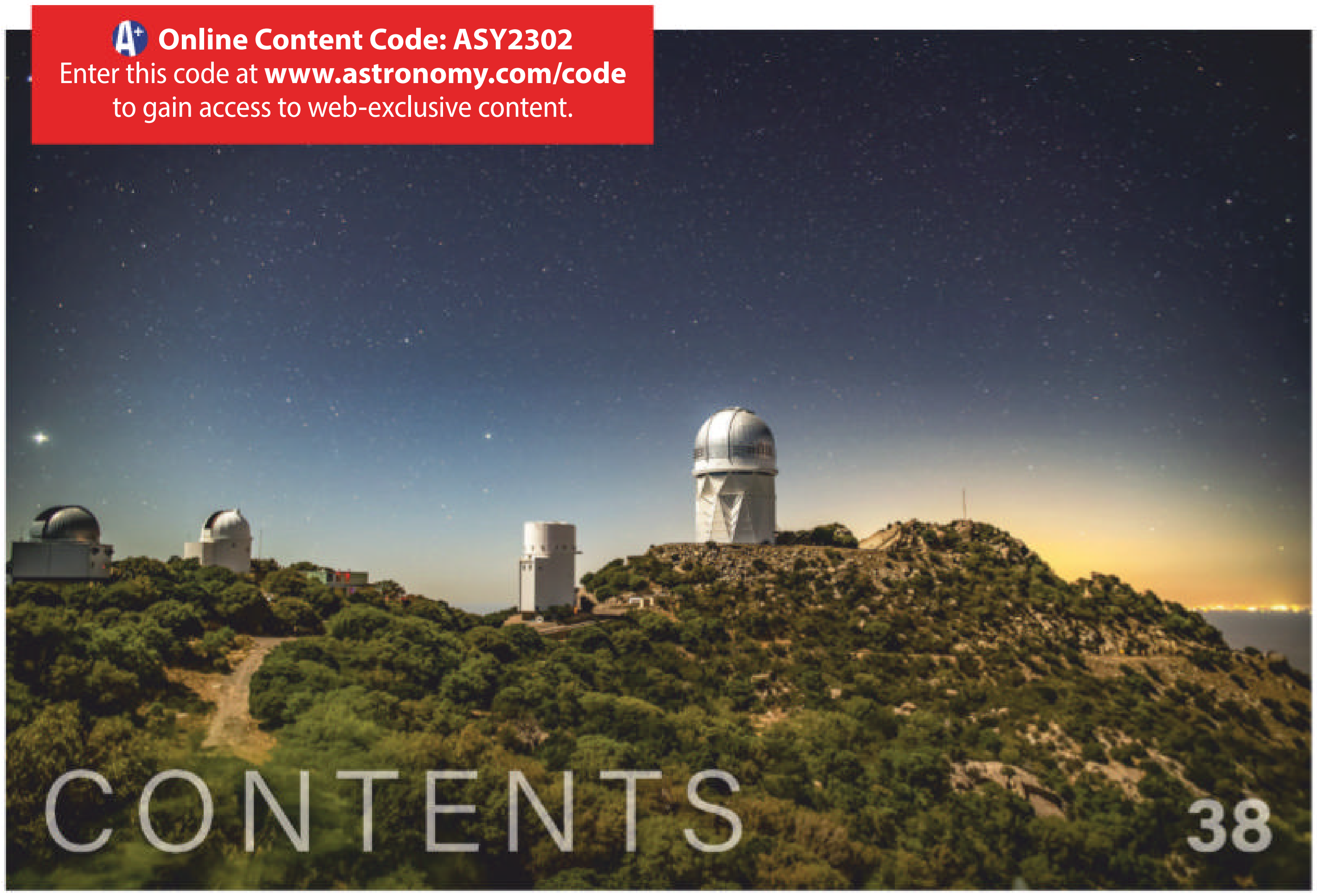

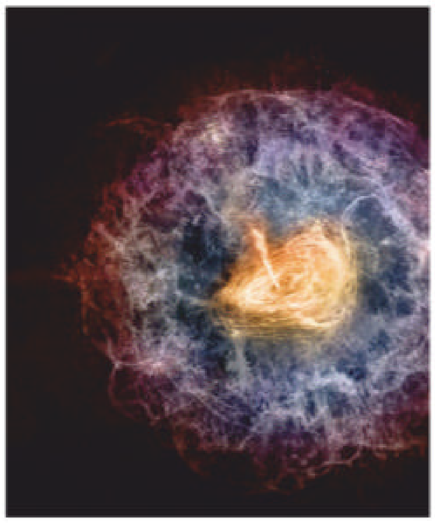

ON THE COVER

This year's hot stories include the discovery of a very young pulsar.

MELISSA WEISS, NRAO/AUI/NSF

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Relaxing fall.

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QUANTUM GRAVITY

Everything you need to know about the universe this month: View a blobby black hole, search for infant planets, get a close-up of Europa, and more.

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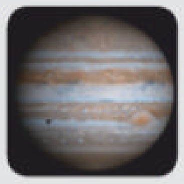

Sky This Week
A daily digest of celestial events.

Ask Astro Archives
Answers to all your cosmic questions.

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FROM THE EDITOR

Observatories, skies, adventures

The 4-meter Mayall Telescope, one of America's workhorse instruments, is now a dedicated dark-energy scope. MARILYN CHUNG/LAWRENCE BERKELEY NATIONAL LAB/KPNO/NOIRLAB/NSF/AURA

This year, one of the great American observatories, the U.S. Naval Observatory in Washington, D.C., celebrates an anniversary. One hundred and fifty years ago, the institution dedicated its great refractor, a 26-inch Alvan Clark instrument that is among the largest refractors in the world. In this issue, astronomer Brian Mason of the USNO describes the illustrious history of that instrument and the observatory overall. Among its highlights are Asaph Hall's 1877 discovery of the martian moons Phobos and Deimos with the 26-inch scope.

Before the observatory moved to its present location, adjacent to the vice president's house along Massachusetts Avenue, the USNO existed down in Foggy Bottom, an area hampered by frequent fog from the Potomac. (The site is a slight distance north of the Lincoln Memorial.) The observatory's early influential superintendent was Matthew Fontaine Maury, the "Pathfinder of the Seas," who eventually became a commander in the Confederate States Navy. I visited the old site years ago and was thrilled to climb up the same small ladder that Abraham Lincoln ascended when he observed along with Hall in August 1863.

In the U.S., the "capital" of astronomy may be said to be Tucson, Arizona. Also in this issue is Randall Hyman's profile of the so-called Tucson Triangle, three major observatory facilities that are among the greatest in the Americas. The Tucson Triangle includes Kitt Peak National Observatory, the Fred L. Whipple Observatory, and Mount Graham, site of the Large Binocular Telescope.

Tucson is a haven for astronomers who are attracted to the centers of research and the pristine, dark skies. Our contributing editor, Michael Bakich, retired to Tucson when he left our staff several years ago. At some point, I will probably follow that path. But not for a little while.

Yours truly,

David J. Eicher
Editor

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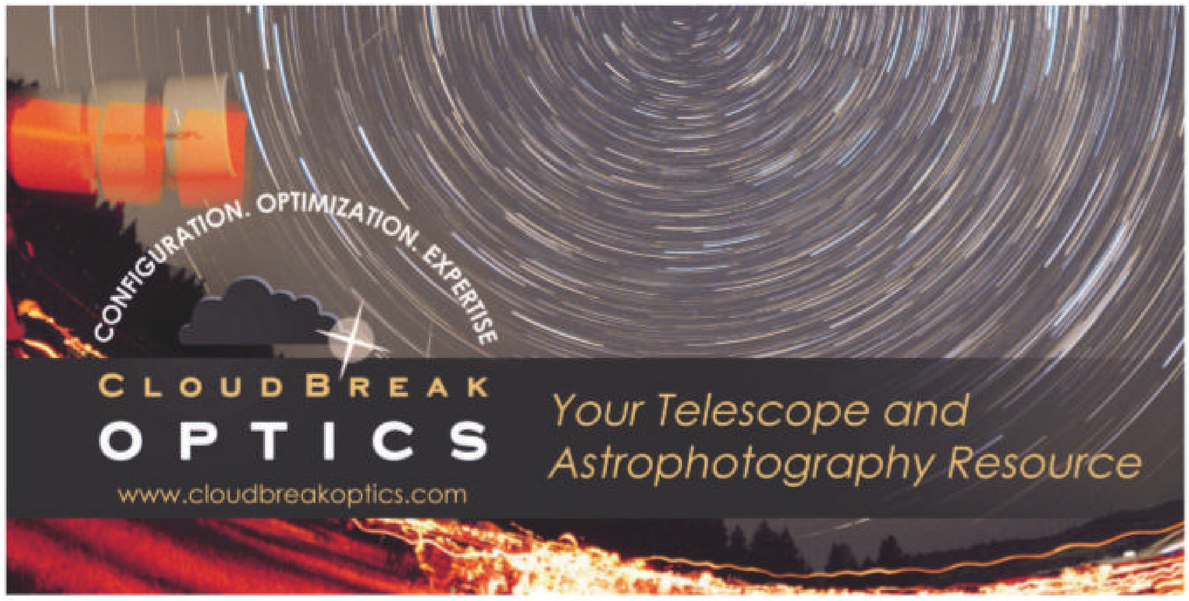

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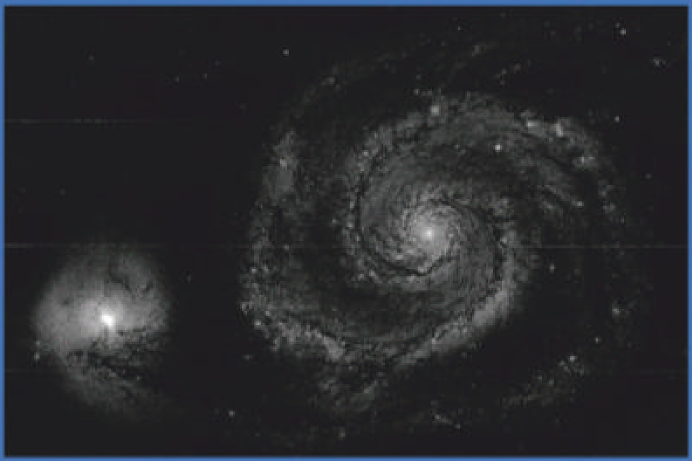

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ASTRO LETTERS

In our poll of favorite JWST images, SMACS 0723 dominated the write-ins. See page 11 for more about this pic. NASA, ESA, CSA, AND STSCI

JWST Top Picks

We asked our Facebook followers: Which JWST image is your favorite? Here are the winners, according to their votes.

1st place: Tarantula Nebula
2nd: NGC 3324 in Carina
3rd: Jupiter and faint rings
4th: NGC 628
5th: Cartwheel Galaxy
6th: Southern Ring Nebula

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

In the comments, the deep field SMACS 0723 was an honorable mention. (The image wasn't included as an option to choose from.) And the most popular response? "All of them!" Photos from JWST are included on pages 7, 14, 23, 36, and elsewhere in this issue.

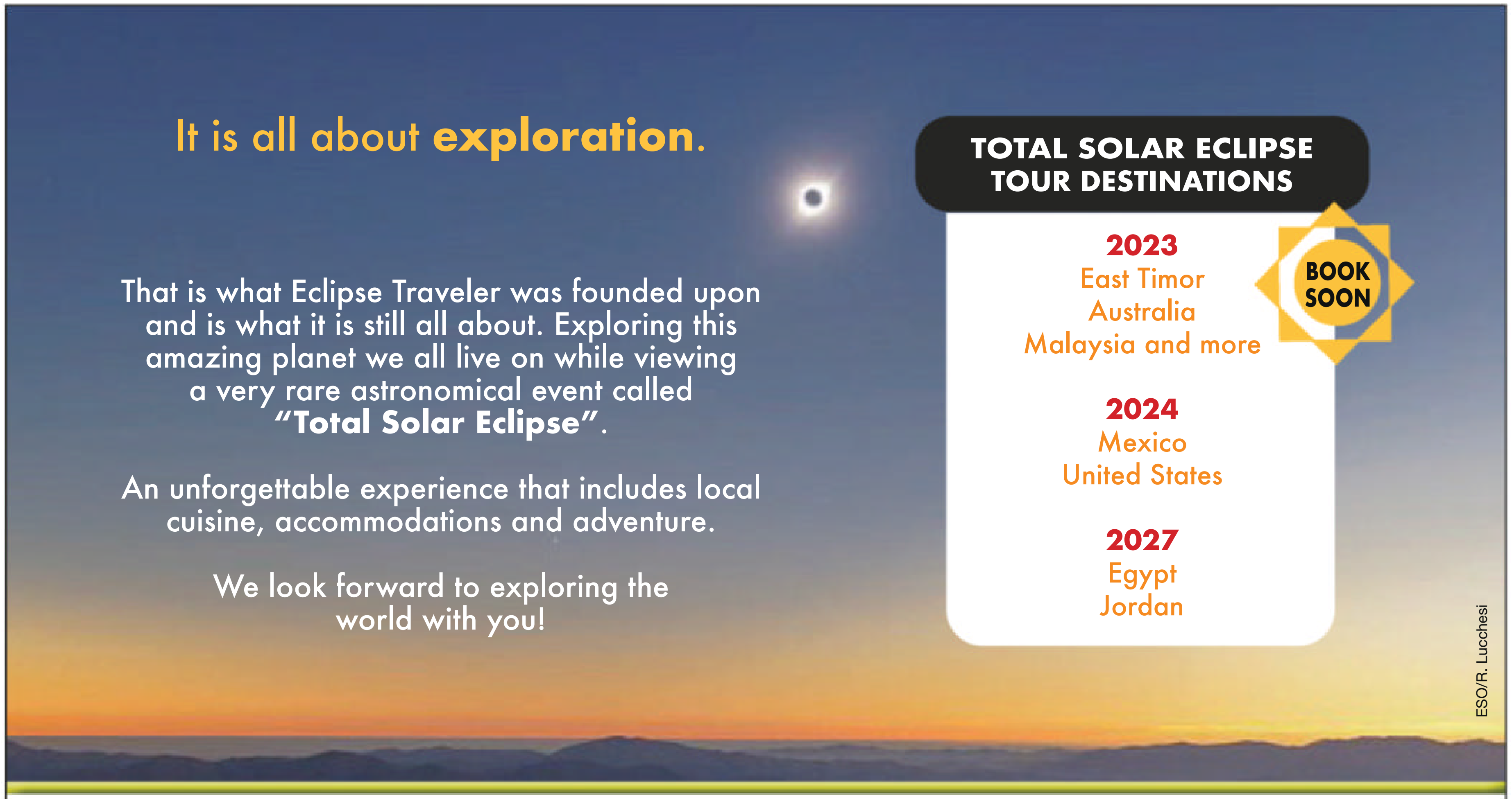
Far, far away

In your Ask Astro section of the October 2022 issue, Farhed Yusef-Zadeh did not answer the question of "How far from Earth would a telescope have to be to capture a direct view of the black hole at the center of the Milky Way, unimpeded by dust clouds?" He pointed out all the reasons we can't see it — it's 26,000 light-years away, dust and gas, etc. However, given that, where would the telescope have to be located for a direct view? **— Jeff Hirsch,** Elmhurst, IL

Associate Editor Caitlyn Buongiorno responds: *The trouble with black holes is that they are, by definition, an absence of light. So, telescopes can never directly see them; instead, astronomers' only option is to view them indirectly via their impact on their surroundings. That's what makes the Event Horizon Telescope so groundbreaking: Scientists have managed to capture images of the shadows of two black holes — from a distance of 53 million light-years in the case of M87* and through the dusty entrails of the Milky Way in the case of Sagittarius A*. And it pulled off the feat without ever having to leave Earth!*

Erratum

The September 2022 issue's From the Editor column mistakenly states that neutron stars have magnetic fields 1,000 times more powerful than Earth's. In actuality, magnetars are neutron stars whose magnetic fields are 1,000 times more powerful than a typical neutron star's — or 1,000 trillion times more powerful than Earth's.



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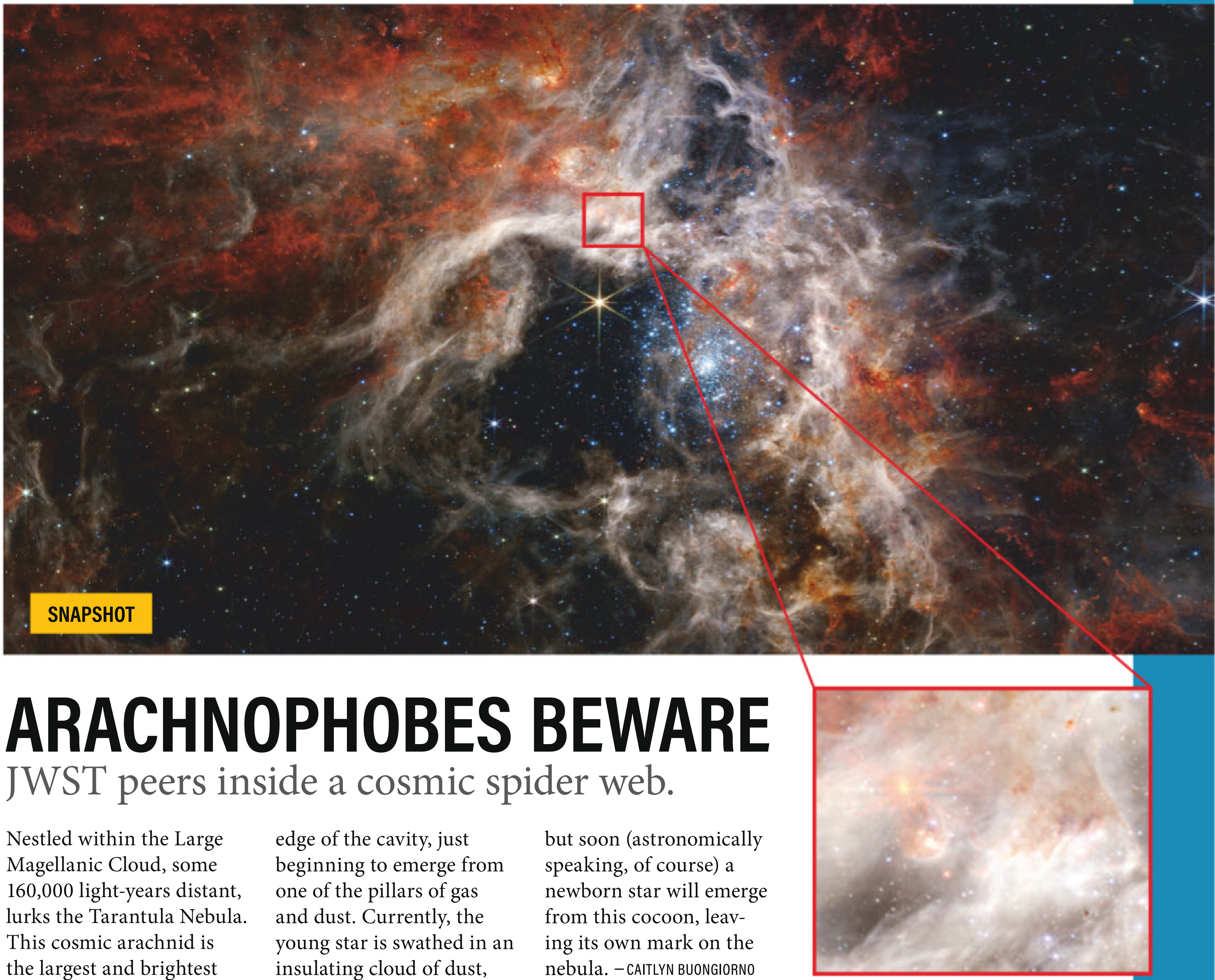
Astronomy

QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH



ARACHNOPHOBES BEWARE

JWST peers inside a cosmic spider web.

Nestled within the Large Magellanic Cloud, some 160,000 light-years distant, lurks the Tarantula Nebula. This cosmic arachnid is the largest and brightest star-forming region in our Local Group of galaxies.

NASA's James Webb Space Telescope (JWST) zeroed in on a stellar egg sac in the Tarantula's burrow for this image. The cavity is being carved out by intense radiation from the massive stars that call it home. One of the most intriguing objects in this region is a still-growing protostar (inset) on the edge of the cavity, just beginning to emerge from one of the pillars of gas and dust. Currently, the young star is swathed in an insulating cloud of dust, but soon (astronomically speaking, of course) a newborn star will emerge from this cocoon, leaving its own mark on the nebula. —CAITLYN BUONGIORNO

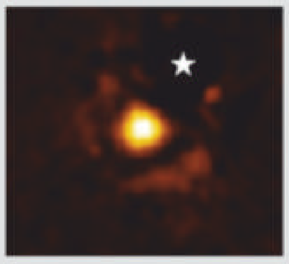
HOT BYTES

SETI PIONEER PASSES

Frank Drake, whose famous equation estimates the number of galactic civilizations capable of interstellar communication, died Sept. 2, 2022, at the age of 92.

BOOSTER FAIL

During an uncrewed launch Sept. 12, Blue Origin's New Shepard rocket booster failed. But the escape system worked perfectly, safely returning the capsule to the ground.



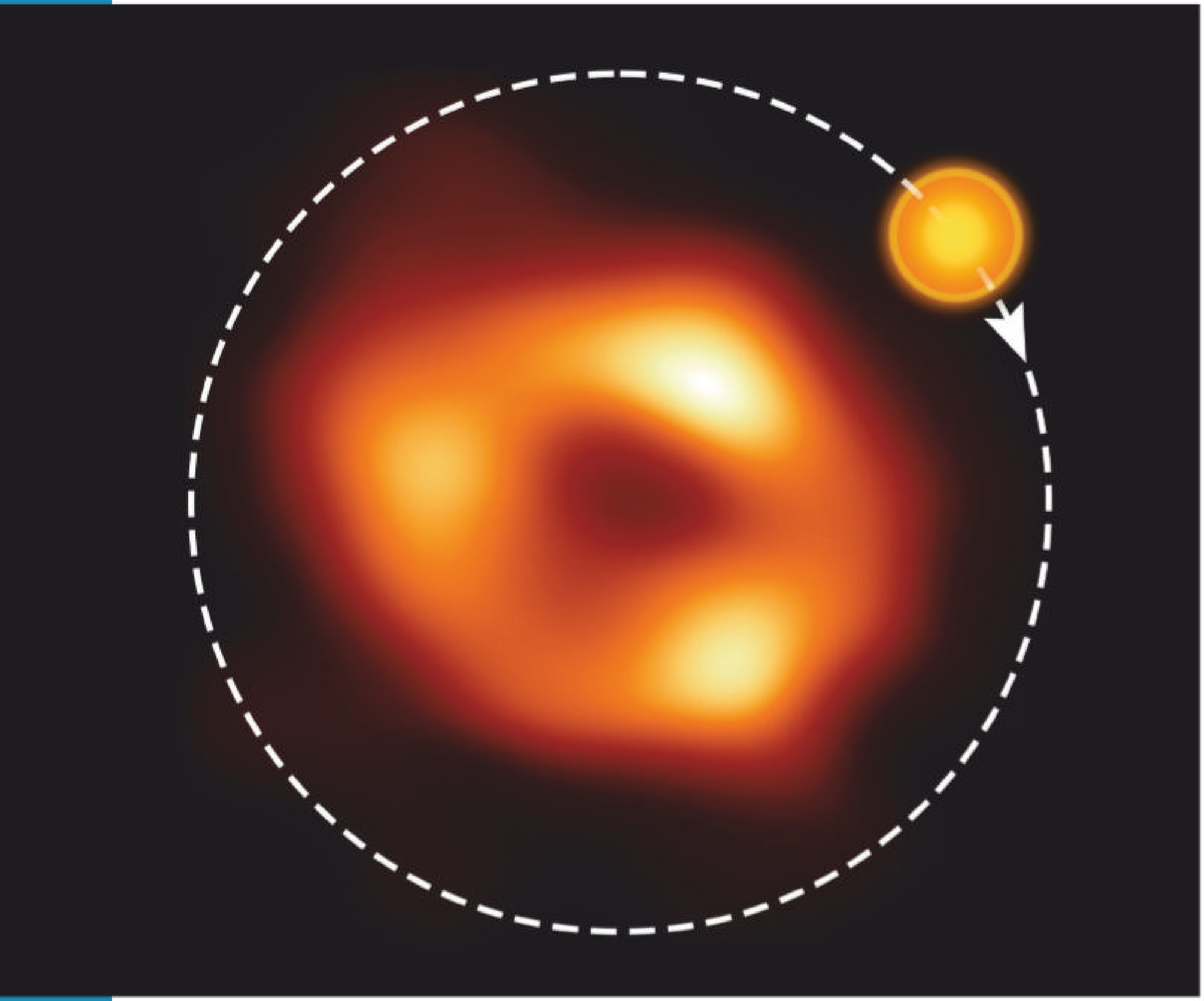
BABY PICTURE

JWST directly imaged its first exoplanet, the young gas giant HIP 65426 b, by blocking out the light of its host star (white star symbol). The world is just 15 million to 20 million years old.

NASA, ESA, CSA, AND STSCI. BOTTOM FROM LEFT: SETI INSTITUTE; BLUE ORIGIN; NASA/ESA/CSA, A CARTER (UCSC), THE ERS 1386 TEAM, AND A. PAGAN (STSCI)

BLOB OF GAS SWIRLS AROUND SAGITTARIUS A*

Corresponding to an X-ray flare, the hot spot has key implications for how our galaxy's supermassive black hole feeds.

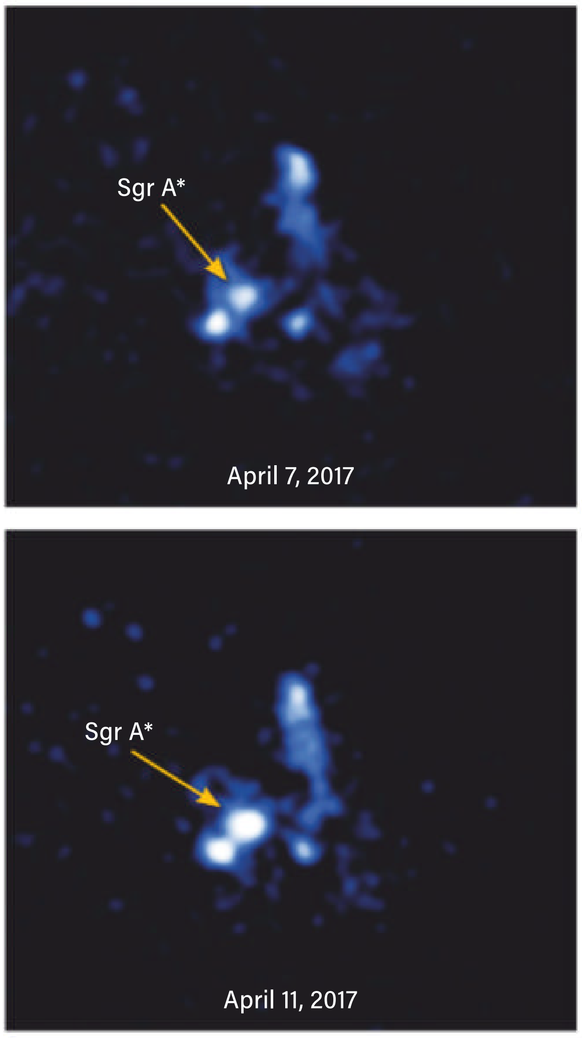


SPIRALING BLOB. While observing the Milky Way's black hole as part of the Event Horizon Telescope in 2017, ALMA spotted a hot bubble of plasma. The location and orbit of the hot spot in relation to Sagittarius A* is shown in this artist's concept. EHT COLLABORATION, ESO/M. KORNMESSER (ACKNOWLEDGMENT: M. WIELGUS)

Tucked away in the heart of the Milky Way galaxy is a slumbering giant known as Sagittarius A* (pronounced "A-star"). While some supermassive black holes are extremely active, devouring large quantities of gas and dust that glow brilliantly in X-rays, Sagittarius A* — or Sgr A* for short — is rather lethargic in comparison.

But, occasionally, Sgr A* will put on a fleeting show.

Astronomers captured one such display in April 2017. During this period, the Event Horizon Telescope's (EHT) network of radio telescopes had its eyes trained on Sgr A*, collecting data to create the first image of our galaxy's supermassive black hole. But the EHT was also joined by an armada of other telescopes in varying wavelengths, as part of a wider campaign to study a variety of aspects of Sgr A*. And, on April 11, NASA's Chandra X-ray Observatory spotted a burst of powerful X-rays (above) from the black hole.



FORTUITOUS FLARE. NASA's Chandra X-ray Observatory watched Sgr A* with the EHT in April, recording an X-ray flare. NASA/CXC/A. HOBART

The Atacama Large Millimeter/submillimeter Array (ALMA) was taking radio observations of Sgr A* for EHT when that X-ray flare occurred, and its data indicated a hot, bright blob was orbiting the black hole. Astronomers think this so-called hot spot is the first detection in radio waves of a counterpart to an X-ray flare from Sgr A*. The observation, published Sept. 22 in *Astronomy & Astrophysics*, also contains clues for how such flares occur.

MYSTERIES ABOUND

Black holes are objects with gravity so strong that not even light can escape. The event horizon, or "surface" of the black hole, marks this boundary of no return. Astronomers can only theorize about what goes on beyond this point.

CTIO/NOIRLAB/DOE/NSF/AURA; T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE/NSF'S NOIRLAB), J. MILLER (GEMINI OBSERVATORY/NSF'S NOIRLAB), M. ZAMANI & D. DE MARTIN (NSF'S NOIRLAB)

COSMIC CRUSTACEAN

Within the constellation Scorpius lies the Lobster Nebula (NGC 6357), located about 8,000 light-years away and photographed here by the Dark Energy Camera on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile. The resulting image of the galactic arthropod showcases swirls of colorful gas, while the open star cluster Pismis 24 peeks out from the center, displaying a host of young, massive stars. To construct the image, researchers captured many shots through different filters before layering them to create a composite. – SAMANTHA HILL

And although we can see the material circling the black hole outside the event horizon, this region isn't free of mysteries, either.

Scientists don't fully grasp what causes flares like these, but suspect the magnetic field surrounding the black hole plays a role. In Sgr A*'s case, researchers think the magnetic field acts as a barrier, preventing the black hole from devouring as much material as it otherwise would. This magnetic blockage causes gas and dust to clump up around the black hole.

Eventually, built-up tension causes one of the magnetic field lines to temporarily break, eliminating the barrier and allowing the black hole to gorge itself. The breakage also releases energy into the surrounding material, forming a hot bubble of plasma.

Initially, these hot spots might primarily emit the X-rays observed during flares, lead author Maciek Wielgus of the Max Planck Institute for Radio Astronomy in Bonn, Germany, tells *Astronomy*. "Maybe it needs a bit of time to cool down to show up at low frequencies corresponding to millimeter [radio] wavelengths," Wielgus says.

A hot spot typically survives for a single orbit before being sheared apart by the black hole's gravity. In this case, the clump of gas zipped around at some 30 percent the speed of light and scientists were able to observe it for 105 minutes before it was torn apart.

"Hopefully, one day," Wielgus said in an ESO press release, "we will be comfortable saying that we 'know' what is going on in Sgr A*." – C.B.

QUICK TAKES

CO_2 DISCOVERY

The James Webb Space Telescope has made the first clear detection of carbon dioxide on a world outside our solar system. The gas is in the atmosphere of WASP-39 b, a hot gas giant orbiting a Sun-like star 700 light-years away in Virgo.

LONG-TERM FORECAST

New high-resolution climate models predict that major observatory sites in Hawaii, Chile, the Canary Islands, Australia, South Africa, and Mexico will experience higher specific humidity (atmospheric moisture content) and temperatures by 2050, potentially leading to reduced data quality.

STELLAR SPIRAL

Surveys of the open cluster NGC 346 in the Small Magellanic Cloud — a good proxy for early galaxies — indicate that its periodic episodes of star formation are triggered by an inflow of stars spiraling toward its center.

WHAT A SAVE!

On Oct. 7, mission controllers managed to recover NASA's CAPSTONE spacecraft from a near-month-long uncontrolled spin. Now CAPSTONE can resume its mission: testing the stability of the unconventional lunar orbit that the Orion spacecraft will use on crewed Artemis flights.

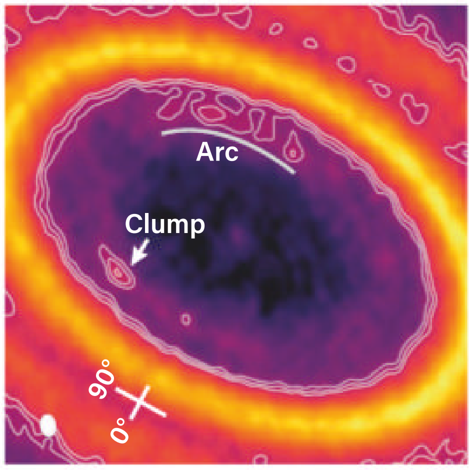
LOST MOON

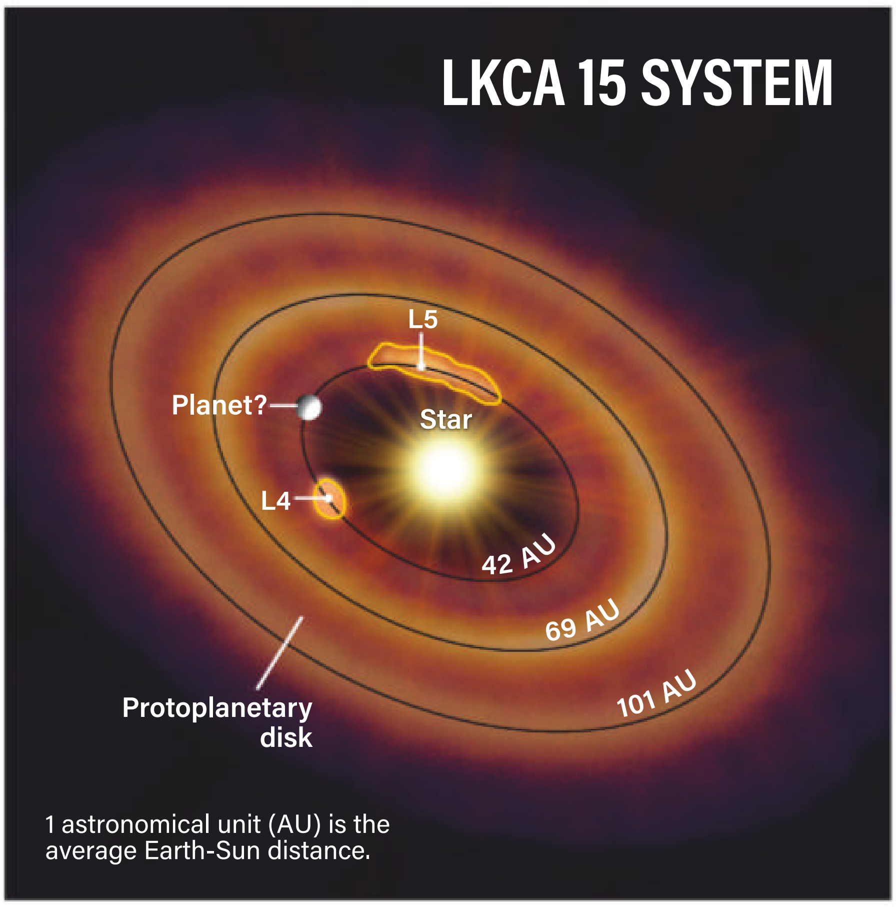
Saturn's rings may be the remains of a moon destroyed 150 million years ago, researchers suggest. Titan could have perturbed a fellow satellite, causing the latter to stray close to Saturn, where it was torn apart by tidal forces.

COLOSSAL SUN-SCOPE

The 4-meter Daniel K. Inouye Solar Telescope, the world's largest, was inaugurated in a ceremony Aug. 31 near the summit of Haleakalā in Hawaii. It will investigate the physics of the Sun, including solar storms that threaten Earth. – MARK ZASTROW

HUNTING BABY PLANETS



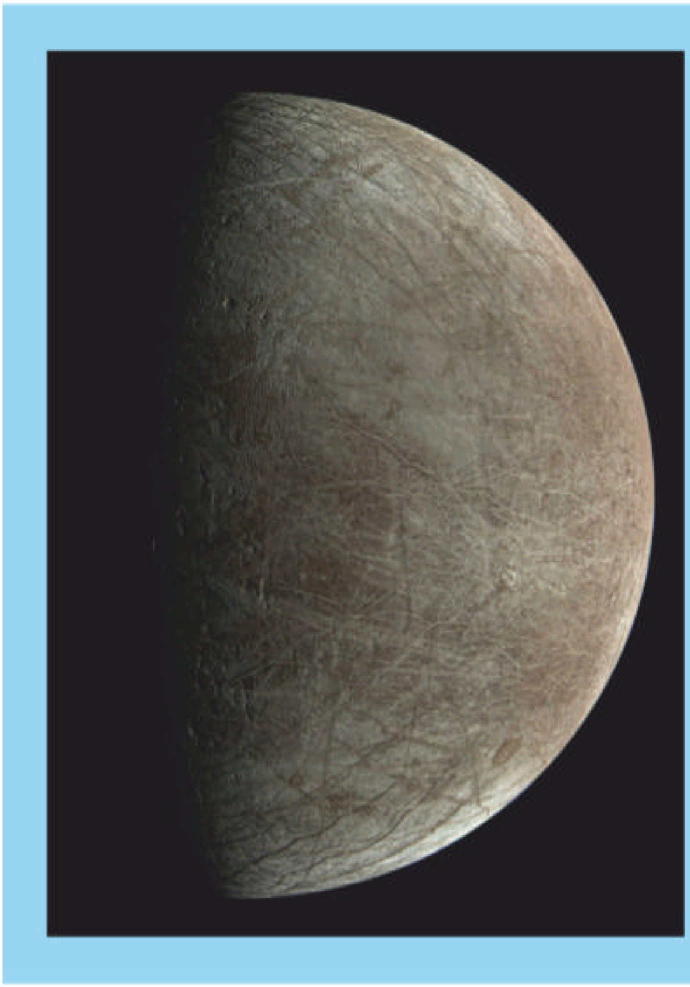


LEFT: FENG LONG ET AL 2022 APJL. RIGHT: *ASTRONOMY*: ROEN KELLY

OVERCOMING DUST. Of the billions of exoplanets that astronomers estimate call the Milky Way home, just over 5,000 have been identified. With such a small sample size, scientists are eager to discover more worlds, including those still forming. This has proven especially difficult, but a new method described in a paper published Sept. 14 in *The Astrophysical Journal Letters* discovered a planet hidden within the dust of the protoplanetary disk LkCa 15 (above). The planet was found by searching for Lagrange points — regions in space where the gravitational pull of two objects balances against the centrifugal force, allowing matter to accumulate. By looking for clumps of material at these locations in the disks around newborn stars, researchers can infer the presence of a forming planet. –C.B.

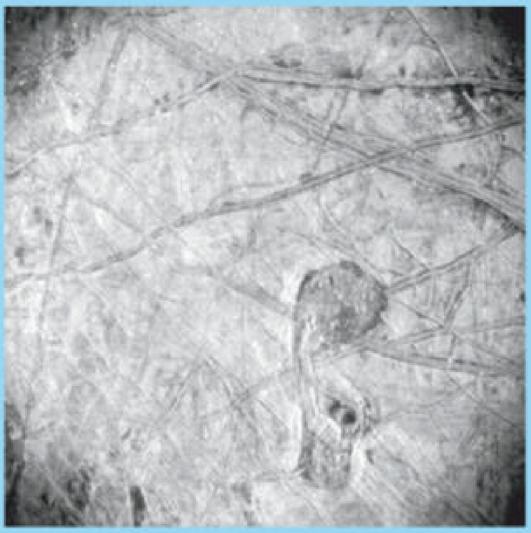
FAST FACT

In the case of LkCa 15, a planet roughly a few million years old and with a mass between Neptune and Saturn is responsible for the clumps of material at the L4 and L5 Lagrange points.

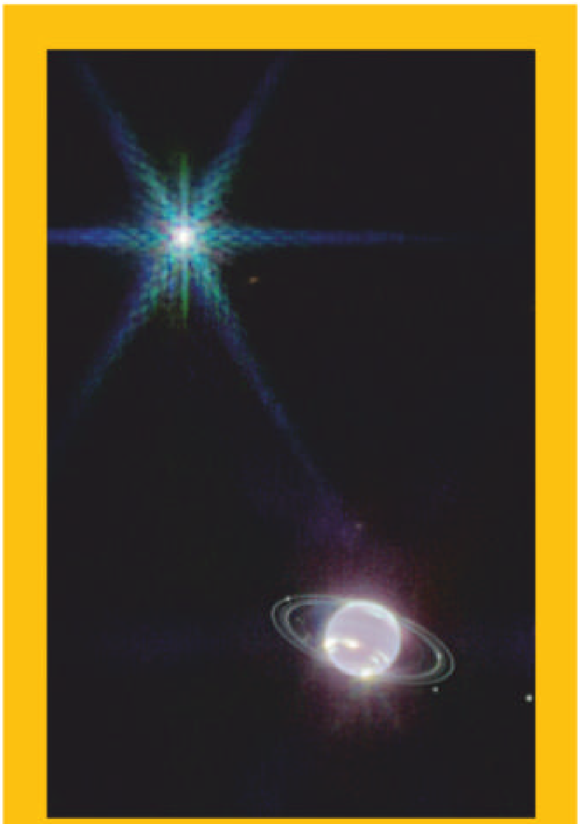


LEFT: IMAGE DATA: NASA/JPL-CALTECH/SWRI/MSSS, IMAGE PROCESSING BY BJÖRN JÓNSSON CC BY-NC-SA 2.0.
RIGHT: NASA/JPL-CALTECH/SWRI

Juno zooms in on Europa



NASA's Juno orbiter captured the dark side of Jupiter's moon Europa during a flyby Sept. 29, 2022. The craft came within 219 miles (352 kilometers) of the moon's surface, obtaining the mission's highest-resolution images of the frozen ocean world. The close-up view (right) is 93 miles by 125 miles (150 km by 200 km), capturing long, hilly tracks jutting out from the surface and, shaped like a musical eighth note, a water-ice blob spanning some 42 miles by 23 miles (67 km by 37 km). The white speckles, reminiscent of snowflakes, are image artifacts caused by the extreme radiation that surrounds the moon. And the dark areas (at the upper right, center right, and lower left) might be an indication of activity below the crust erupting onto the surface. –S.H.

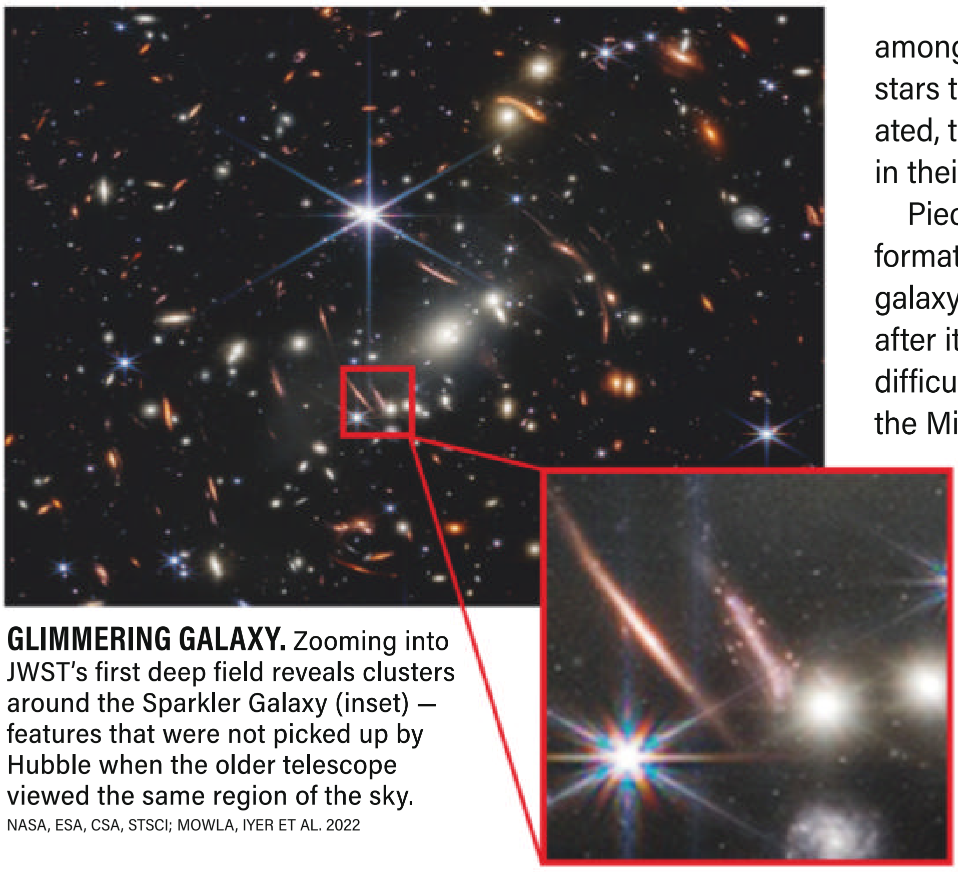


NASA, ESA, CSA, STSCI; IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI), NAOMI ROWE-GURNEY (NASA-GSFC)

JWST SPIES NEPTUNE'S RINGS

At 30 times farther from the Sun than Earth, Neptune isn't easy to photograph. But NASA's James Webb Space Telescope (JWST) was able to capture the clearest image of Neptune's features — including its ethereal ring system — since Voyager 2 flew by the distant world in 1989. The ice giant's relative surplus of gaseous methane gives it a characteristic blue hue in visual images. But because methane gas strongly absorbs the wavelengths of light that JWST's Near-Infrared Camera (NIRCam) is sensitive to, Neptune appears surprisingly dim in this image, outshone by its largest moon, Triton (top left). Methane ice high in Neptune's atmosphere, meanwhile, better reflects sunlight, resulting in the bright streaks and spots visible on the planet's disk. –JAKE PARKS

Galaxy sparkles with earliest-known globular clusters



GLIMMERING GALAXY. Zooming into JWST's first deep field reveals clusters around the Sparkler Galaxy (inset) — features that were not picked up by Hubble when the older telescope viewed the same region of the sky.
NASA, ESA, CSA, STSCI; MOWLA, IYER ET AL. 2022

The first image ever released from the James Webb Space Telescope (JWST) teems with thousands of galaxies, including some shining when the cosmos was less than a billion years old. These early galaxies are made visible by the immense mass and gravity of the galaxy cluster at the center, SMACS 0723, which bends light from behind it like a lens, magnifying distant objects.

And, for astronomers, the 9-billion-year-old light from one sticks out.

The galaxy, nicknamed the Sparkler, is now the subject of a paper published Sept. 29 in *The Astrophysical Journal Letters*. "When we were looking at the first image of the Webb's Deep Field, some people in the team noticed that there was this galaxy that looks like it has a bunch of sort of shiny dots around it," study co-author Kartheik Iyer, a postdoctoral fellow at the University of Toronto, tells *Astronomy*. "[One of us] started calling it the sparkly sparkler and the name stuck."

But what are these so-called sparkles?

The 12 compact objects are either young, actively forming star clusters or much older globular clusters. So far, the team was able to identify five as the latter. This makes the Sparkler's globulars among the earliest stars the universe created, the team writes in their paper.

Piecing together the formation history of a galaxy billions of years after its birth can be difficult. For instance, the Milky Way has around 150 globular clusters, which might initially seem like an extraordinarily large sample size. But astronomers don't quite understand precisely how and when these clumps of stars formed. "Think of it as guessing a person's age based on their appearance," said co-author Lamiya Mowla, a Dunlap Fellow at the Dunlap Institute for Astronomy & Astrophysics at the University of Toronto, in a press release. "It's easy to tell the difference between a 5 and 10 year old, but hard to tell the difference between a 50 and 55 year old."

The Sparkler's clusters were formed about as early as possible in the lifespan of the universe. This means that scientists are seeing the globulars at a much younger age than the ones in the Milky Way, which makes the Sparkler's clusters easier to date.

The team was able to identify five of the compact objects as globular clusters, but there's still more work to be done. Although the researchers have been able to associate all 12 objects with the Sparkler Galaxy, they haven't yet been able to confirm whether the other seven are also globulars. At least not yet.

Being able to identify more globular clusters could allow astronomers to apply techniques to the early universe that they have so far only used in the local universe, Iyer notes. "It's this entire field of analysis that opens up." –C.B.

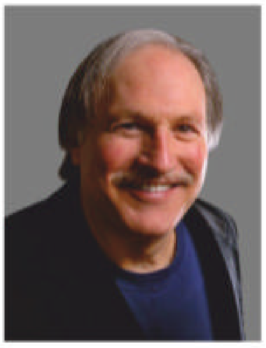
STRANGE UNIVERSE

Stages of astro-coping

Or: How not to deal with bad seeing.

As dreams of a clear, star-filled sky slip away, what is an observer to do?

ALLEXXANDAR/DREAMSTIME



BY BOB BERMAN

Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

In 1969, Elisabeth Kübler-Ross introduced her five stages of grief experienced by people who are facing life's tragedies. But those five now-famous stages — denial, anger, bargaining, depression, and acceptance — have been overlooked by backyard astronomers.

Say you're an observer in a typical suburban location. You've spent a small fortune on a telescope that looks so cool, you gaze at it like it's a Rembrandt. Tonight, you've invited over an old friend you'd like to impress; you've heard she owns some mountaintop acreage, and you fantasize she'll let you build an observatory there. So you aim your telescope at Saturn, arguably the universe's greatest crowd-pleaser.

The five now-famous stages have been overlooked by backyard astronomers.

But to your horror, it's not there. In its place is a wiggly smudge that resembles an amoeba on amphetamines. You're tempted to explain that the problem is called "bad seeing," but you're too bummed to form coherent sentences. As you sense your mountaintop observatory slipping away, you're overwhelmed with grief at the loss of your dreams. So perhaps Kübler-Ross can come to the rescue. You mentally scroll through her list and remember her first item: denial. Worth a try.

"Nothing's wrong with Saturn," you explain as your friend squints through the eyepiece. "Instead, Earth's atmosphere is animating it through the gift of turbulence, the same helpful gaseous motion that makes you puke on a jetliner. After all, if Saturn were motionless, it might seem lifeless and sterile."

But a glance at your unimpressed visitor suggests you try something else. "Bad seeing is actually a venerable astronomy tradition," you say with a touch of pride. "When Galileo had conditions like this in 1610, it made him sketch Saturn as a ball that had two handles attached, an illustration that's been prized for centuries. See if you can visualize the planet the way he did — as a sugar bowl!"

"A sugar bowl?"

"Yes! And we could even see even more history-making sights if I had an observatory on a mountaintop somewhere," you subtly hint. But you're not succeeding and it's making you irritated. Anger, you suddenly realize, is next on the list of stages. That must be the key!

"This sucks!" you loudly bellow, making your companion leap backward. Creatively, you decide to channel that Kübler-Ross-approved rage toward your next-door neighbor, who just installed security floodlights brighter than prison watchtowers. You grab your phone and leave him a message citing legal property rights, the Dark Sky Association, and Italian phrases you think sound intimidating but later realize are just cookbook expressions like *al dente*.

So, forget that. You turn to the next stage: bargaining! Okay, but with whom? You've not been to church in years and, anyway, you don't have anything valuable to offer the Creator in exchange for steadying the atmosphere — so you settle on bargaining with a used telescope website. You dial their number and when someone answers, you start haggling, knowing smaller apertures are better in turbulence. "I'll trade you my 6-inch Dob for a 2-inch handheld, telescoping spyscope," you offer.

But wait! If you end up with just a tiny instrument, why would your friend give you land for an observatory? "Never mind!" you shout into the phone, ending the exchange with a confused after-hours janitor who'd assumed that by "Dob," you'd been trying to give him your Doberman pinscher. And now you're down to the penultimate grief-assuaging strategy: depression.

As you fall into a deep malaise, you suddenly realize what astronomers have known for 413 years: Wiggly, depression-inducing seeing is so widespread, you have no choice in the matter. A smile creeps across your face, the expression common to observers through the centuries. Finally, you know its name and cause.

It's called acceptance!

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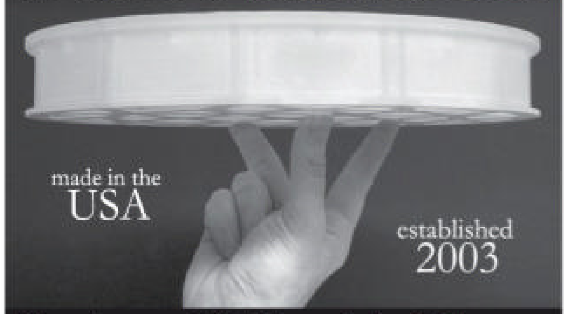
Performance.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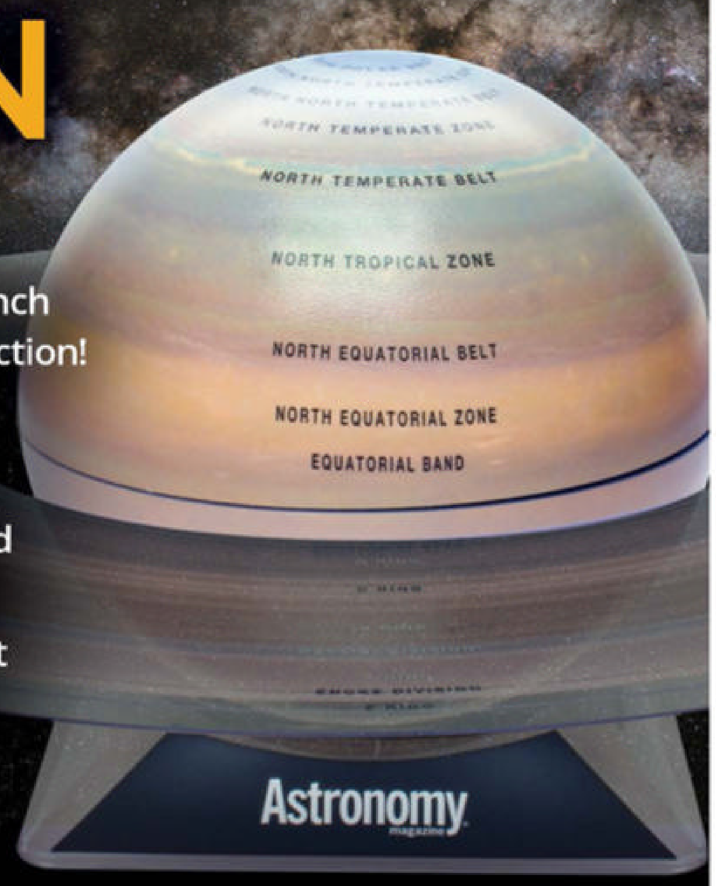
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TOP 10 SPACE STORIES OF 2022

Last year kicked off the era of JWST, while astronomers mapped out the next decade of discovery and released some of the first results from the Hayabusa2 mission to asteroid Ryugu.

BY ALISON KLESMAN

SCIENCE IS SUCH A FORWARD-LOOKING endeavor that it's all the more rewarding when long, challenging efforts finally come to fruition. And 2022 was a year with many payoffs, as researchers began unlocking the secrets of our solar system's asteroids and received rich maps of the stars that populate the Milky Way.

Excitement reigned as we moved an asteroid from 6.8 million miles (11 million kilometers) away. New and intriguing phenomena popped onto the scene, proving we still have much to understand about our universe. And two groundbreaking stories stole headlines, as we finally glimpsed the monster black hole at

The star-forming region NGC 3324 within the Carina Nebula was among JWST's first publicly released images. NASA, ESA, CSA, STSCI

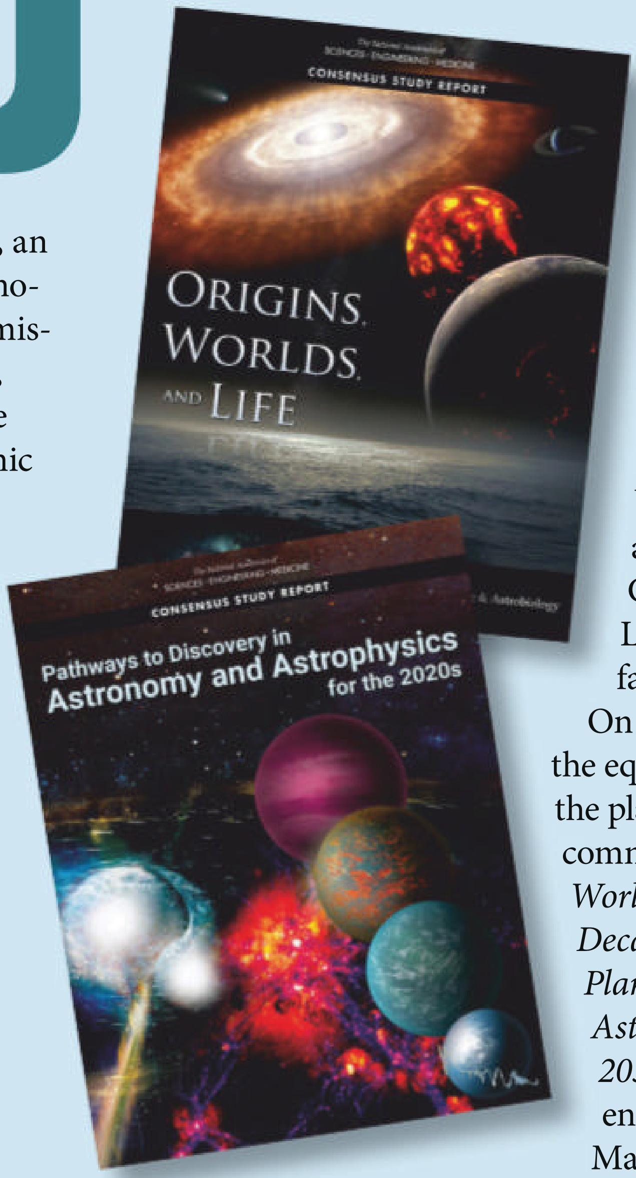
the heart of our galaxy and received the first stunningly sharp images from humanity's most challenging and risky space telescope effort to date.

It was also a year for reflection, as landmark missions drew to a close. Yet even as opportunities end, others are waiting around the corner, and astronomers are always ready to seize them.

BOOKS: NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE

10

Astronomers release 10-year wish lists


CONSENSUS STUDY REPORT
ORIGINS, WORLDS, AND LIFE
CONSENSUS STUDY REPORT
Pathways to Discovery in Astronomy and Astrophysics for the 2020s

EVERY 10 YEARS, an expert panel of astronomers considers how missions are performing, where changes can be made, and what cosmic questions astronomy should focus on for the next decade. Their findings are called the decadal survey. Although not a strict rulebook, the survey is considered by agencies such as NASA when choosing how to spend limited budgets.

Delayed a year by the COVID-19 pandemic, the National Academies of Sciences, Engineering, and Medicine released *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, also called Astro2020, on Nov. 4, 2021. Its 615 pages outline top pursuits in observational and theoretical astronomy, broken into three main focuses. They are: exoplanets and stars, including finding and characterizing Earth-like worlds; formation and evolution of stars and galaxies, particularly how they are intertwined; and multi-messenger astronomy, which combines observations across the electromagnetic spectrum.

One major recommendation is the creation of the Great Observatories Mission and Technology Maturation Program to focus on the development of an $11-billion 6-meter combination infrared/optical/ultraviolet space telescope and, later in the decade, additional $3-billion and $5-billion missions to study the far-infrared and X-ray regimes, respectively.

The committee also suggests investing in the Giant Magellan Telescope and Thirty Meter Telescope, the CMB Stage 4 observatory to study signals left by the Big Bang, and the Next Generation Very Large Array radio facility.

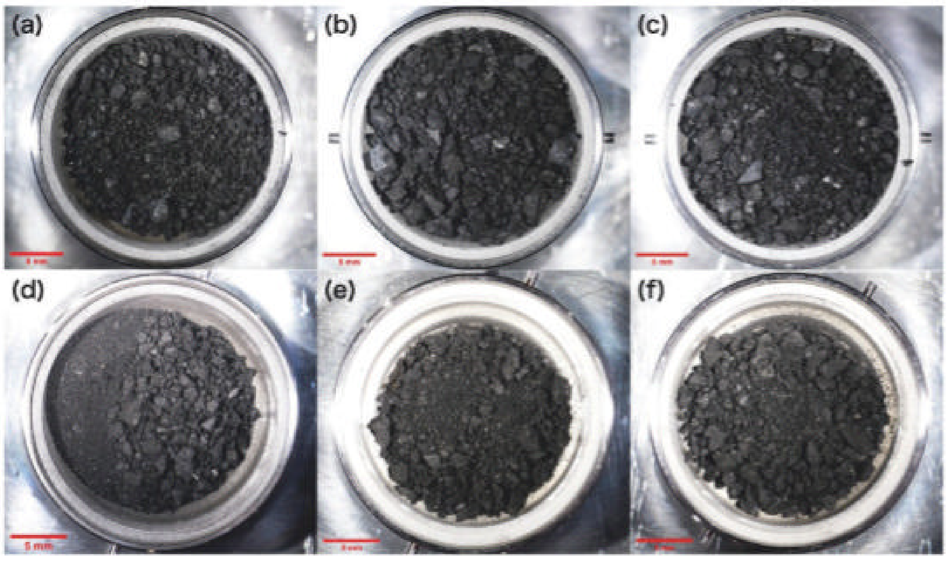
On April 19, 2022, the equivalent report for the planetary science community, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*, was released. It endorses NASA's Mars sample-return mission and the Endurance-A rover, which will cache material from the lunar south pole for astronauts to retrieve. The report also recommends funding development of a mission to fly past a near-Earth object to help us better prepare for impact threats. Over the longer term, the committee supports missions to comets, asteroids, and moons. Large-scale undertakings prioritized by the report include the Uranus Orbiter and Probe and the Enceladus Orbilander.

The survey also includes the first "state of the profession," discussing diversity and equity in planetary science and astrobiology. While acknowledging progress in these areas, "much work remains to be done, in particular to address persistent and troubling issues of basic representation by race/ethnicity."

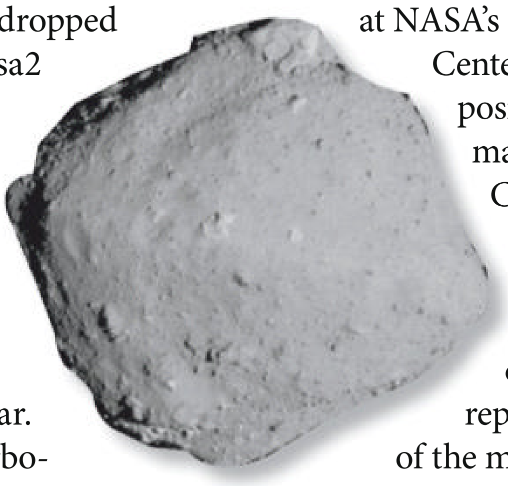
Recommendations in hand, it is now time for funding agencies to decide where and how to allocate resources in the coming years.

9

First results are rolling in from Ryugu



ABOVE: Precious grains from asteroid Ryugu, collected by the Hayabusa2 spacecraft in 2019, have begun making their way to labs around the world for analysis. YADA ET AL., *NATURE ASTRONOMY*, 2021



LEFT: The surface of the near-Earth asteroid Ryugu is porous and shows signs of assembling early in the solar system's history. JAXA, UNIVERSITY OF TOKYO, KOCHI UNIVERSITY, RIKKYO UNIVERSITY, NAGOYA UNIVERSITY, CHIBA INSTITUTE OF TECHNOLOGY, MEIJI UNIVERSITY, UNIVERSITY OF AIZU AND AIST

IN 2019, the Japan Aerospace Exploration Agency's Hayabusa2 collected a total of 0.19 ounce (5.4 grams) of material from both the surface and subsurface of the near-Earth asteroid 162173 Ryugu. The craft delivered its samples to Earth Dec. 6, 2020, via a re-entry capsule dropped off as Hayabusa2 zipped past.

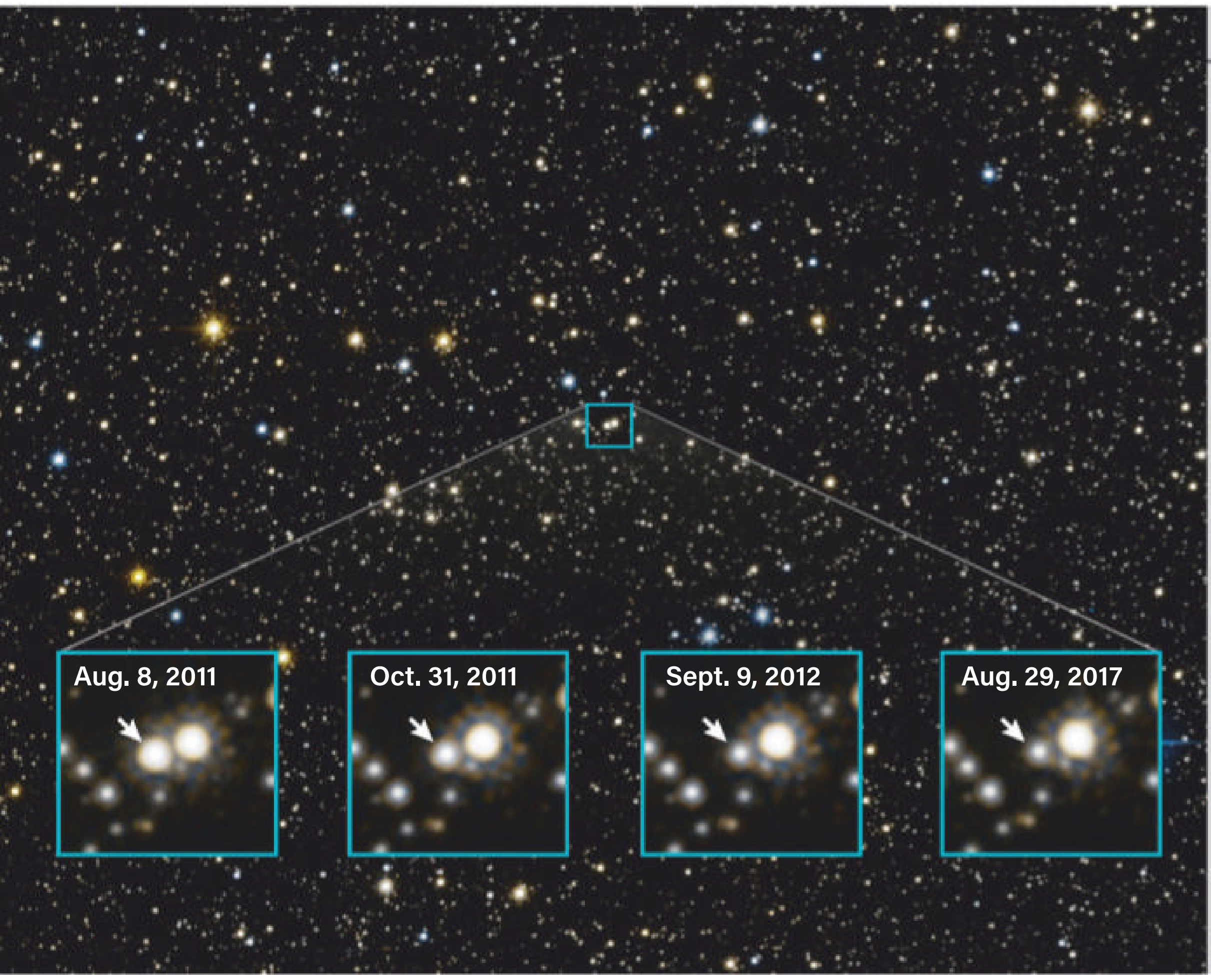
Starting in late 2021, the results of researchers' initial analyses began to appear. Ryugu is a carbonaceous or C-type asteroid, rich in both water and organic (i.e., carbon-based) material. Early studies found that Ryugu's particles have been heavily altered by water. Their low density has led researchers to surmise that the boulders covering much of the surface are highly porous.

"Ryugu samples are the most chemically pristine materials ever analyzed in the lab," says Ann Nguyen, a planetary scientist in the Astromaterials Research and Exploration Science Division at NASA's Johnson Space Center. Their composition closely matches that of CI chondrite meteorites, which have been long considered representative of the material that formed the Sun and solar system.

"Ryugu likely came from a larger precursor asteroid that was several tens of kilometers in size," Nguyen adds, which studies have determined "formed beyond Jupiter, and beyond Ryugu's current orbit." One study, led by former graduate student Kaitlyn McCain and postdoc Nozomi Matsuda, working with Kevin McKeegan at the University of California, Los Angeles, discovered hints that its parent formed quickly in the early stages of our solar system's assembly. "It's really hard to know when the asteroids were put together," McKeegan says. "This has implications for models about how things would accrete in the early solar system."

Another study, published June 10 in the *Proceedings of the Japan Academy* by a team at Okayama University in Japan, found features of interstellar material predating our solar nebula, as well as amino acids within Ryugu's organic material. Those authors suggest Ryugu's parent may have been a comet whose composition was altered as passes through the inner solar system boiled away its ices, leaving behind a porous, rocky body.

"This mission was really, to my mind, fantastically successful," McKeegan says. One thing is clear: Ryugu has much to teach us about its past.



7

Researchers (possibly) find a rogue black hole

ASTRONOMERS HAVE MAPPED numerous black holes throughout our galaxy — all in binary systems, visible only through interactions with a neighbor. Lone, quiet black holes are hard to find.

As an invisible compact object — potentially a lone black hole — passed in front of a background star (indicated with an arrow) in the Milky Way, the black hole's gravity caused the star's light to temporarily brighten. NASA, ESA, AND KAILASH SAHU (STSCI); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

8

Gaia Release 3 offers a data deluge

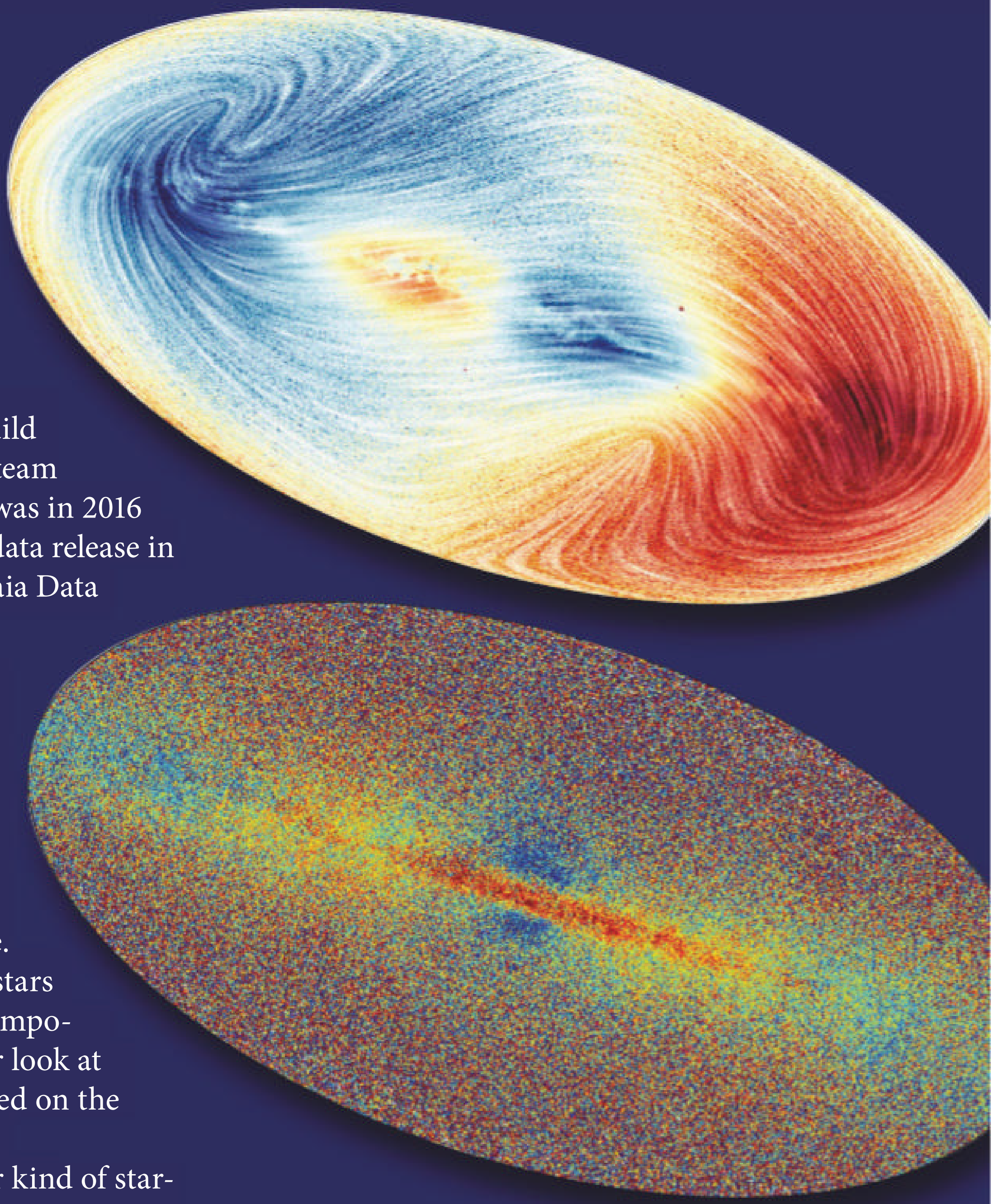
THE EUROPEAN SPACE AGENCY'S Gaia satellite has the ambitious goal of surveying billions of Milky Way stars to build a three-dimensional map of our galaxy. Every few years, the team puts out a data release, or catalog of measurements; the first was in 2016 and the second in 2018. Following a preliminary early third data release in late 2020, astronomers were eagerly awaiting the complete Gaia Data Release 3 (DR3) from the mission.

Finally, on June 13, 2022, ESA published the full DR3. Among its contents are the classifications, temperatures, and distances for nearly 1.6 billion objects; the 3D motions of 33 million stars; a 3-million-pixel map of galactic dust; observations of more than 10 million variable stars, eclipsing binary systems, transiting exoplanets, and supermassive black holes; and measurements of some 158,000 solar system objects, such as asteroids and moons. And there's much more.

Alongside the release came stunning maps showing how stars orbit and move within the Milky Way, and their chemical composition. These new details allow researchers a better-than-ever look at how, where, and when the stars in our galaxy were born, based on the elements they contain and their motions through space.

The team also discovered that Gaia can detect a particular kind of starquake, which ripples through the star and distorts its normally spherical shape. Many were seen in stars not expected to show them, and astronomers are eager to decipher the strange behavior.

DR3 has already triggered a slew of papers on topics ranging from our solar system to far-flung galaxies, as well as a dedicated special issue of *Astronomy & Astrophysics* detailing the data and their potential. And there will be many more to come, as researchers get the chance to really dig in.



These all-sky maps from the Gaia DR3 show the line-of-sight motion (top) and chemical composition (bottom) of millions of Milky Way stars. In the top map, blue colors show motion toward us, while red shows motion away from Earth. On the lower map, redder colors depict younger stars that have been enriched in heavier elements by previous generations (bluer) of stars. ESA/GAIA/DPAC; CC BY-SA 3.0 IGO

That changed Jan. 31, when a paper uploaded to the *arXiv* preprint server reported a black hole wandering solo. The path to this detection began in 2011, when a massive, dark object passed between Earth and a star near the Milky Way's bulge. For 270 days, the star brightened as its light was bent and focused by the mass of the intervening object — a process called gravitational microlensing. This piqued the interest of researchers hunting for free-floating, or rogue, black holes. Astronomers think there may be hundreds of millions such objects in the Milky Way; although they give off no light, they could be found through microlensing.

Heavier objects cause longer microlensing events. But duration alone is not enough to definitively weigh the intervening object. So, researchers used the Hubble Space Telescope to precisely measure the star's apparent position for six years. The amount it seemed to shift in the sky gave a much more robust solution for the lens' mass. Their conclusion: The interloper is a black hole between 5.8 and 8.4 solar masses. "The object we detected is so massive that if it were a star, it would be shining brightly; yet we detected no light from it," says study leader Kailash Sahu of the Space Telescope Science Institute in Baltimore. Sahu's team published their results July 6 in *The Astrophysical Journal*.

But a separate team led by Casey Lam and Jessica Lu of the University of California, Berkeley, also studied the event. Their analysis of the Hubble data, published the same day in *The Astrophysical Journal Letters*, found the lens is between 1.6 and 4.4 solar masses. Anything so dark above 2.2 solar masses can only be a black hole, but a lighter object in this range is more likely a neutron star. "As much as we would like to say it is definitively a black hole, we must report all allowed solutions. This includes both lower-mass black holes and possibly even a neutron star," Lu said in a press release.

The teams hope further observations of the background star — whose position is still offset slightly — taken in fall 2022 will soon distinguish between models, putting the mystery to rest.

GETTING ARTEMIS OFF THE GROUND

ON AUG. 29, 2022, NASA's massive Space Launch System (SLS) rocket, topped with an uncrewed Orion capsule and an additional payload of 10 tiny CubeSats, sat ready to launch Artemis I — the first step in the next era of U.S. lunar exploration — from Cape Canaveral, Florida. The mission's goal was simple: Send Orion around the Moon and back over the course of about two weeks, releasing the satellites along the way to complete their own lunar science missions.

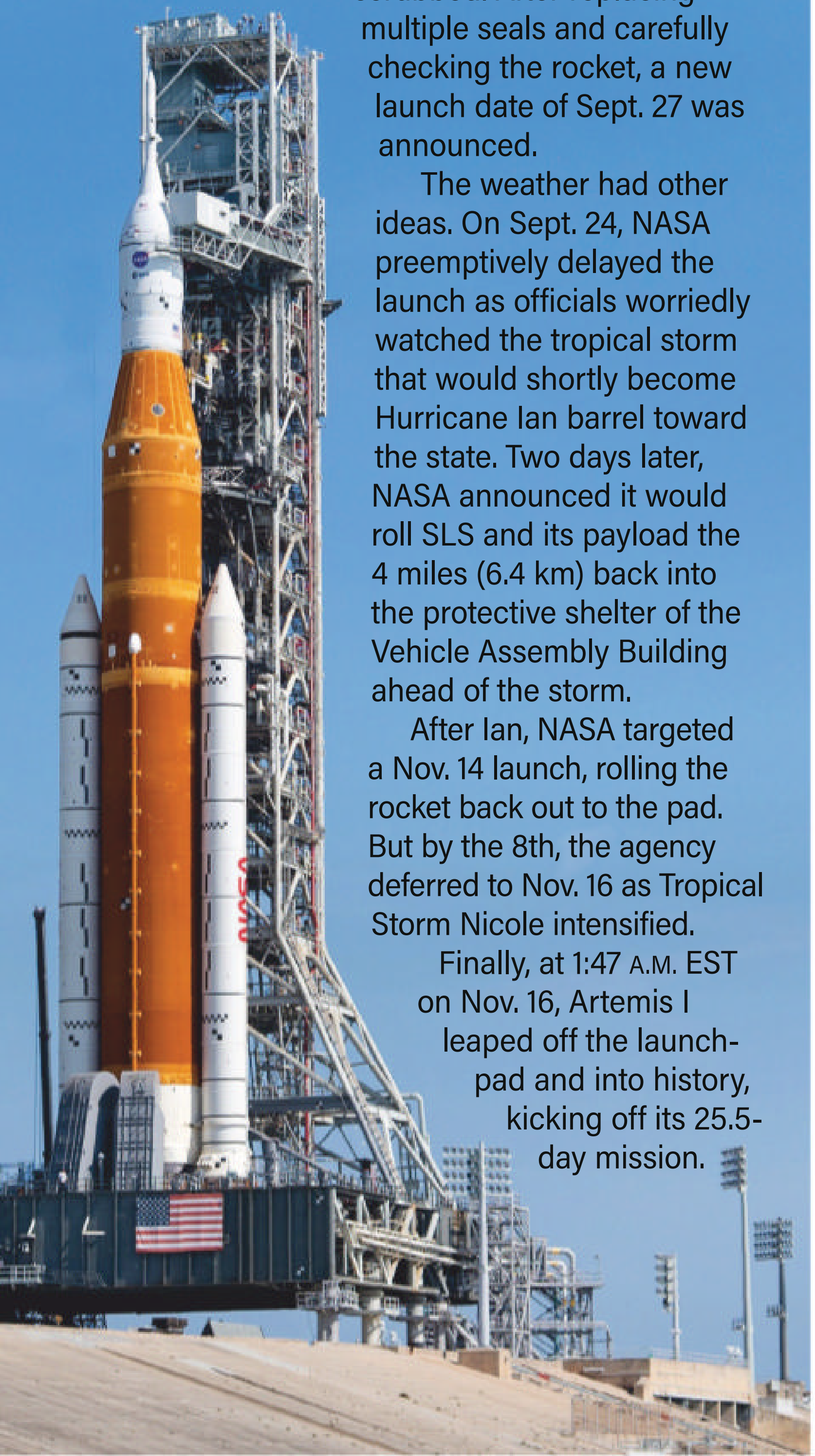
But 40 minutes before liftoff, the launch was held ... and then scrubbed. Officials discussed several reasons for the halt, including a leak in a liquid hydrogen fueling line and, more concerning, the failure of one of SLS's RS-25 core stage engines to reach the proper temperature during pre-launch cooling. Ultimately, engineers ran out of time to troubleshoot as the two-hour-long launch window closed.

NASA next set Sept. 3 for launch, but again during fueling, the rocket experienced a recurring liquid hydrogen leak and the attempt was scrubbed. After replacing multiple seals and carefully checking the rocket, a new launch date of Sept. 27 was announced.

The weather had other ideas. On Sept. 24, NASA preemptively delayed the launch as officials worriedly watched the tropical storm that would shortly become Hurricane Ian barrel toward the state. Two days later, NASA announced it would roll SLS and its payload the 4 miles (6.4 km) back into the protective shelter of the Vehicle Assembly Building ahead of the storm.

After Ian, NASA targeted a Nov. 14 launch, rolling the rocket back out to the pad. But by the 8th, the agency deferred to Nov. 16 as Tropical Storm Nicole intensified.

Finally, at 1:47 A.M. EST on Nov. 16, Artemis I leaped off the launchpad and into history, kicking off its 25.5-day mission.



NASA/JOEL KOWSKY

6

Exoplanets near and far

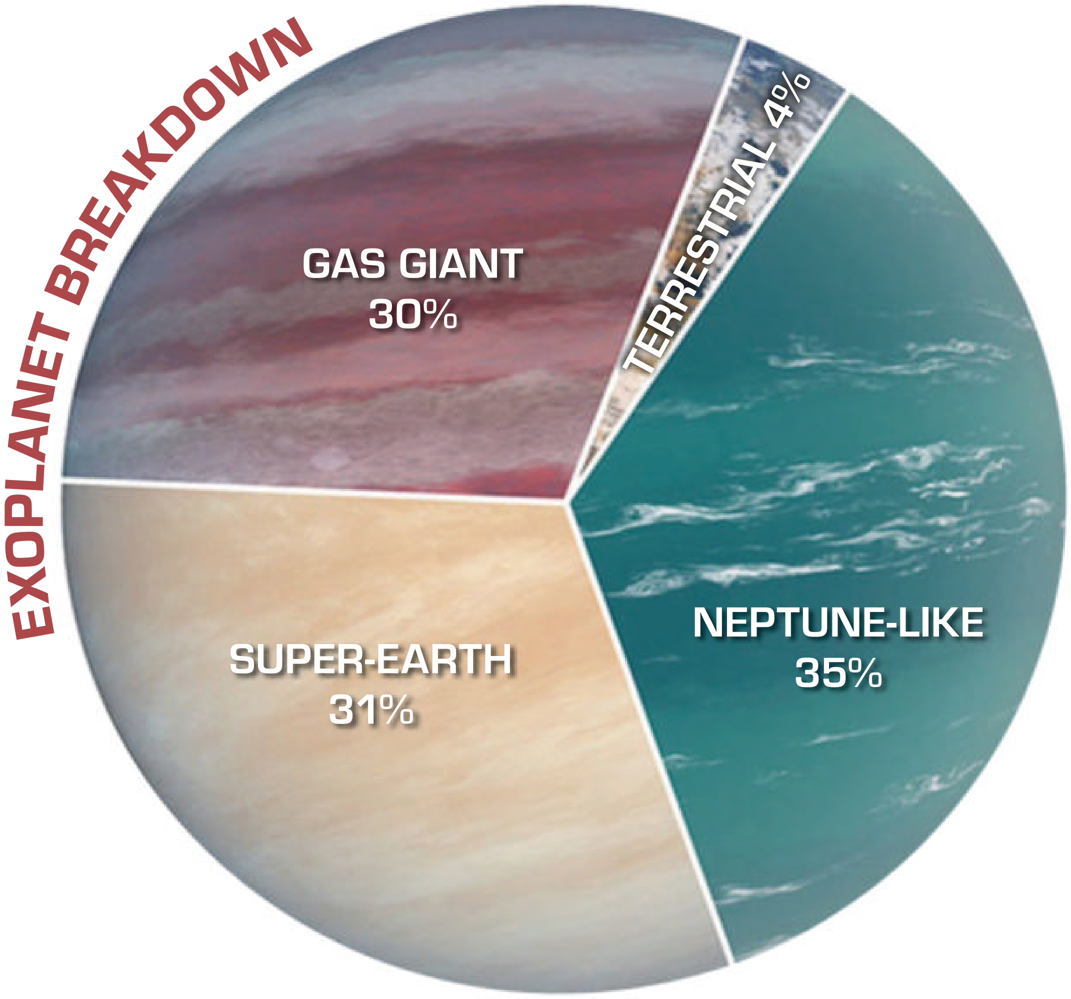
2022 WAS ANOTHER banner year for exoplanets. On Feb. 10, astronomers reported a third possible planet around our nearest stellar neighbor, Proxima Centauri, just 4 light-years away. Called Proxima d, it joins the Earth-mass world Proxima b, spotted in August 2016; and Proxima c, a super-Earth reported in January 2020.

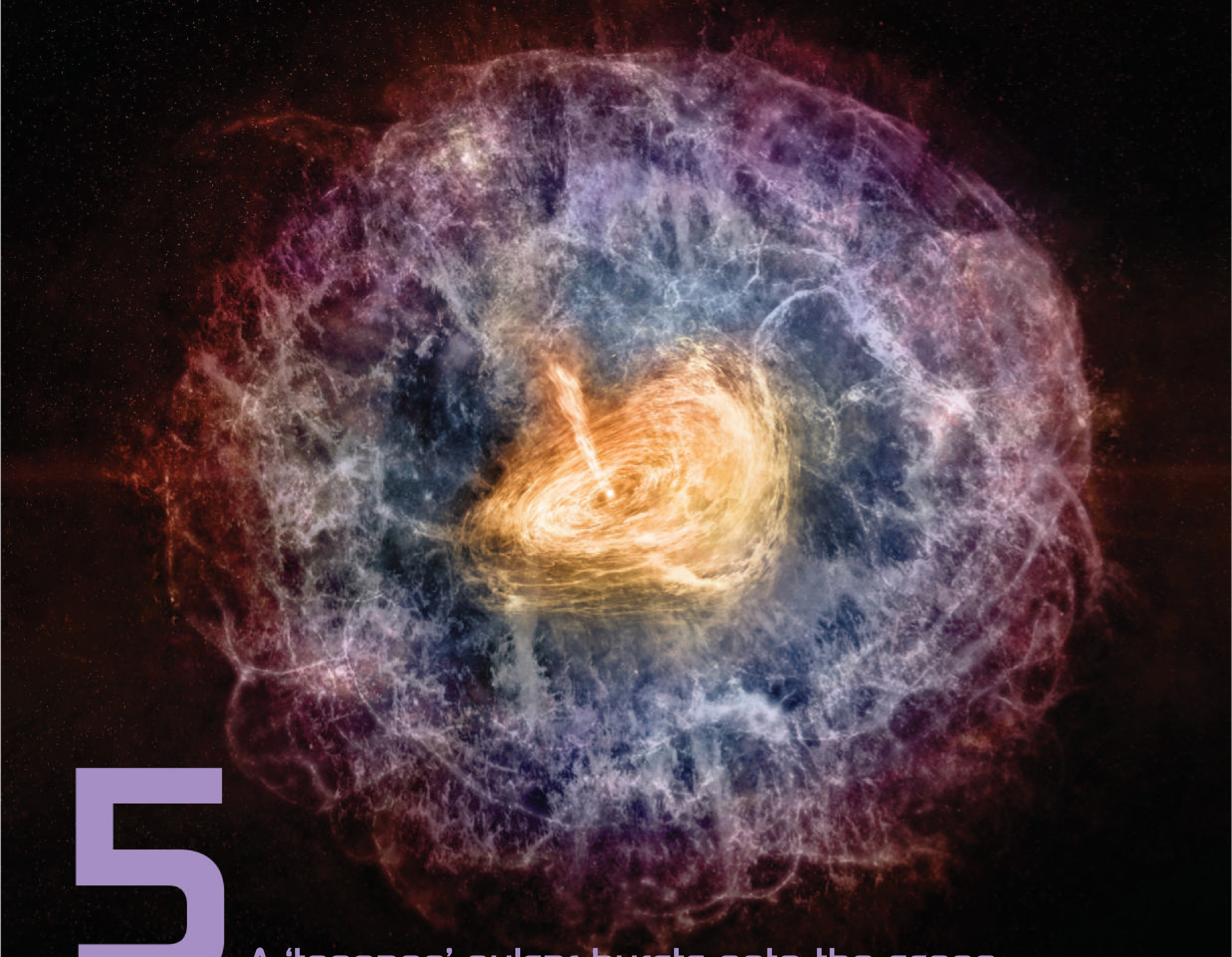
Based on observations from the European Southern Observatory's Very Large Telescope in Chile, Proxima d is just one-quarter the mass of Earth. It orbits once every five days some 2.7 million miles (4.3 million km) from its star — less than one-tenth Mercury's distance from the Sun. Because Proxima Centauri is only 12 percent the Sun's mass and 14 percent its diameter, Proxima d (like Proxima b, but not c) lies in its habitable zone, where conditions could support surface water.

For now, Proxima d and c remain planetary candidates awaiting confirmation with follow-up observations. While many candidates are ultimately confirmed as planets, some are instead found to be starspots, noise in the data, or even brown dwarf companions. But if confirmed, they'll be in good company: Just a month after Proxima d's discovery was published, NASA announced March 21 that the astronomical community had confirmed a total of 5,000 extrasolar planets. That's a huge accomplishment for a field born roughly 30 years ago.

Now, researchers are excited to make the switch from simply racking up increasing numbers of planets to exploring their properties, including habitability. In particular, new tools such as the recently launched James Webb Space Telescope and ESA's upcoming Ariel satellite will give us a closer look than ever before at the atmospheres of the worlds circling the myriad stars of our Milky Way.

With more than 5,000 exoplanets confirmed, researchers can break them into broad categories. Some 30 percent are gas giants like Jupiter or Saturn; roughly 35 percent are Uranus- or Neptune-like; and just 4 percent are rocky, terrestrial planets like Earth. Many exoplanets (31 percent) are super-Earths or mini-Neptunes, which fall between the mass of Earth and Neptune and may be rocky or support thick, puffy atmospheres. Such planets have no analogue in our solar system. *ASTRONOMY*: ROEN KELLY, AFTER NASA/JPL-CALTECH





5

A ‘teenage’ pulsar bursts onto the scene

A young pulsar wind nebula (yellow) becomes visible as the shell of debris from the supernova that created it (blue, purple, red) expands and thins in this artist’s impression. MELISSA WEISS, NRAO/AUI/NSF

WHEN A MASSIVE STAR DIES, it goes out with a bang, sometimes leaving behind a rapidly spinning neutron star, known as a pulsar. These throw off high-speed winds of particles that move outward to form a bubble in their surroundings, called a pulsar wind nebula. There’s one at the heart of the Crab Nebula (M1), the remnant of a supernova some 1,000 years ago.

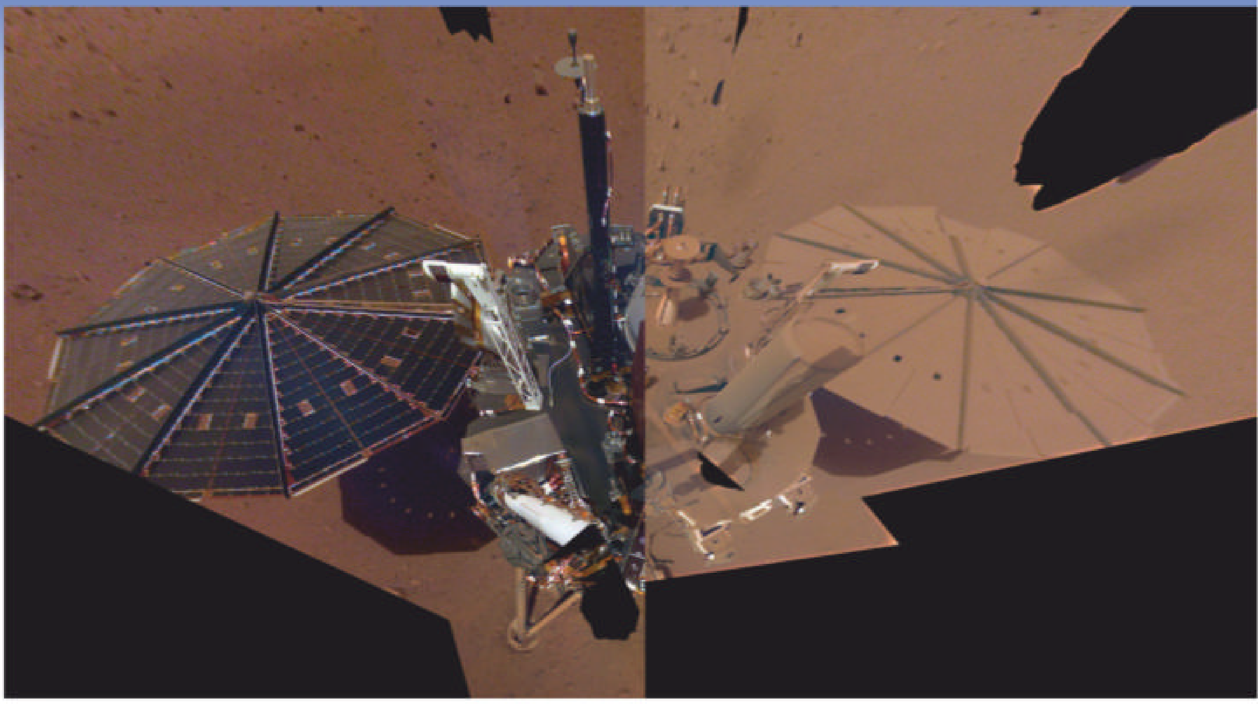
But that’s old news. Recently, we got a much younger example — perhaps the youngest ever discovered. Estimated to be between 14 and 80 years old, the newcomer, called VT 1137-0337, lies in a dwarf galaxy 395 million light-years away. Astronomers first picked up its radio emission in 2018 in data from the Very Large Array (VLA) Sky Survey. It also appears in data from 2019, 2020, and 2022. But when the team went back to VLA observations of the same galaxy from 1998, there was no sign of it.

That means VT 1137-0337 has only recently become visible. Researchers tested several theories to explain the emission, from a supernova to a star falling into a black hole. Ultimately, says Dillon Dong, a Caltech graduate student who announced the find June 15 at the American Astronomical Society’s summer meeting and the lead author of a paper submitted to the *Astrophysical Journal*, “the most plausible origin of this nebula seems to be a pulsar wind, or potentially flares from a magnetar,” a type of super-magnetic neutron star. But, he notes, no radio nebulae have ever been detected around a magnetar, so he thinks it’s more likely a pulsar wind nebula. And the reason it’s suddenly popped up is that the nebula had been embedded within the debris of the supernova that created the neutron star. Only over time has that material expanded and thinned, finally allowing VT 1137-0337’s light to shine through.

VT 1137-0337 is some 10,000 times more energetic than the Crab and has a more powerful magnetic field. And “this thing is young enough that we can actually see it evolve on a human timescale,” Dong says. VT 1137-0337’s emission has faded 20 percent in just four years. In some 1,000 years, he adds, it will probably look like the pulsars and magnetars we’re used to finding around the Milky Way. So, this is a unique peek at the earliest stages of a neutron star’s life. For now, his team will continue monitoring VT 1137-0337 as well as use additional wavelengths to learn more about its properties. They will also look in existing and future survey data in the hopes of finding similar nebulae.

4

Landmark missions come to a close



NASA's InSight lander accumulated so much martian dust that its solar panels could no longer provide enough power. Comparing InSight's first selfie (left) in 2018 with its last (right) in 2022 shows how much dust settled onto the lander over time. NASA/JPL-CALTECH

WHILE 2022 OPENED many new doors, it was a time of closure as well. In April, NASA and the German Space Agency announced they would shut down the Stratospheric Observatory for Infrared Astronomy (SOFIA), which carried a 2.5-meter telescope aboard a Boeing 747SP airplane. Most infrared (IR) light is absorbed by water in Earth's atmosphere. SOFIA flew above 99 percent of that water, allowing observations of the entire IR spectrum — a range even the James Webb Space Telescope cannot match. "SOFIA found its own niche … and used it to do science that isn't possible from anywhere else," says SOFIA instrument scientist Pete Ashton.

But the Astro2020 decadal survey (see No. 10) stated SOFIA's yearly operating price tag of $86 million USD — on par with the Hubble Space Telescope and Chandra X-ray Observatory — could not be justified by its "modest" scientific output. From 2014 to 2020, SOFIA flights resulted in 178 scientific papers; Hubble and Chandra data combined were used in more than 2,700 papers over the same period. So, on Sept. 28/29, SOFIA made its last flight from Palmdale, California.

"The loss of SOFIA simply means loss of access to the far-IR window for at least the next 10 years," says Dario Fadda, a senior scientist at the SOFIA Science Center. He also worries researchers who might have worked on SOFIA's IR data will move to other fields. But other astronomers, such as SOFIA principal engineer Nancy McKown, are hopeful such work won't suffer long. "There may be some gaps now, but I'm confident that the thirst for knowledge will keep it in the long view of the big picture. After all, the data will still be there for us to capture in the future."

3

NASA smacks an asteroid

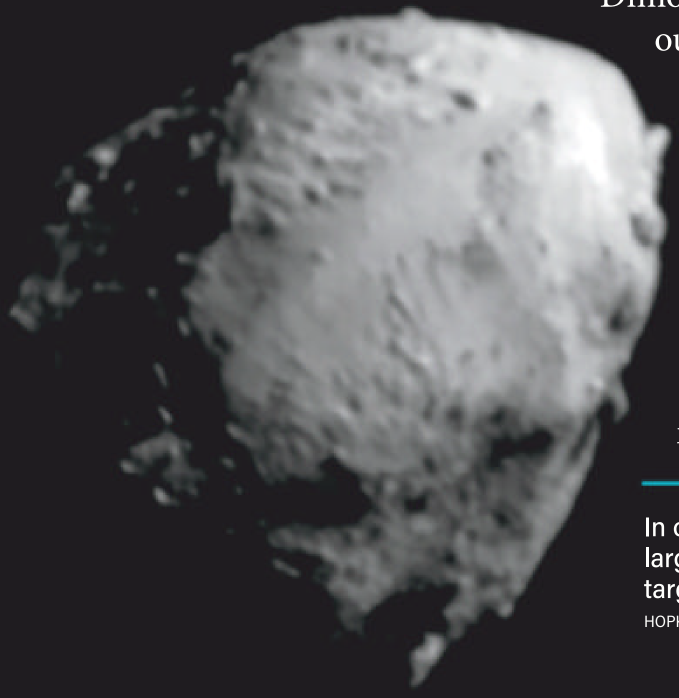
AT 7:14 P.M. EDT ON MONDAY, SEPT. 26, 2022, a 1,260-pound (570 kilograms) spacecraft traveling 14,000 mph (22,530 km/h) slammed directly into a small asteroid named Dimorphos, throwing out a massive cloud of debris.

The (pre-planned) hit was the culmination of NASA's Double Asteroid Redirection Test (DART) to determine whether a "kinetic impact" — i.e., hitting an asteroid with a spacecraft — could alter its trajectory. The hope, should it work, was that a similar technique could be employed to redirect an asteroid on a collision course with Earth.

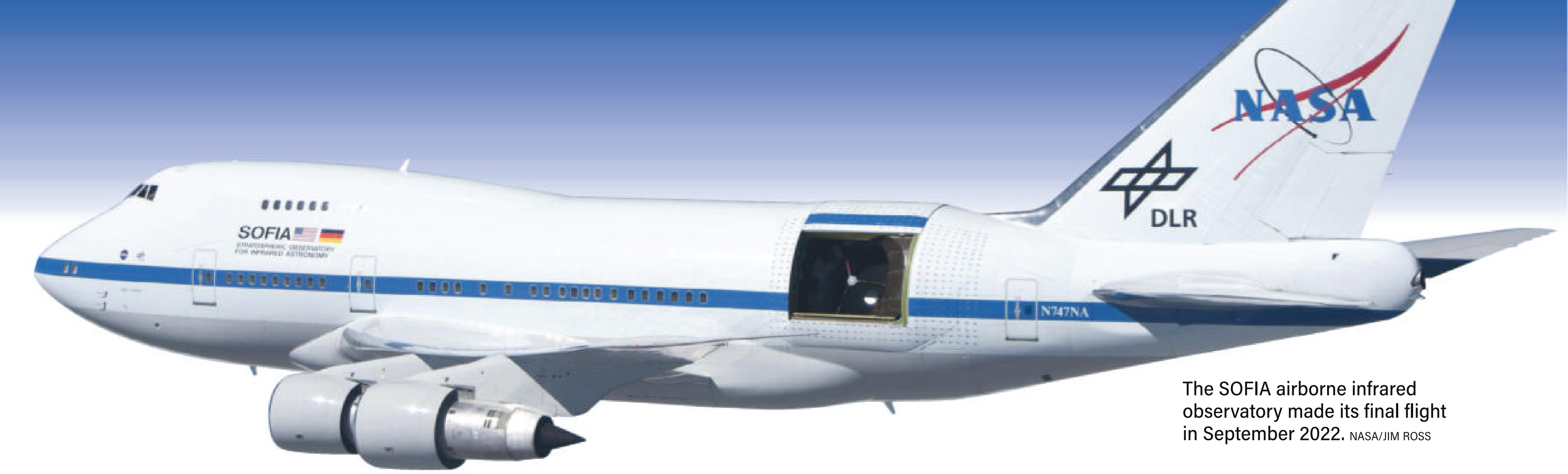
The test target, 525-foot-wide (160 meters) Dimorphos, is a moonlet orbiting the near-Earth asteroid (NEA) 65803 Didymos, which is roughly 0.5 mile (780 m) across. DART's goal was to slightly shrink the orbit of Dimorphos around Didymos. Success would be measured by whether the impact altered Dimorphos' nearly 12-hour period by at least 73 seconds.

On Oct. 11, NASA announced that Dimorphos' 11-hour and 55-minute orbit had shortened to 11 hours and 23 minutes. The difference, 32 minutes, was roughly 26 times the mission's baseline for success.

It was a watershed moment in the field of planetary defense, which aims to identify and mitigate risks to Earth from asteroids and comets that may cross our planet's path. (It's worth noting that of the more than 29,000 known NEAs in late 2022, none pose a significant risk. But there are likely many more yet to be found.) "As new data come in each day, astronomers will be able to better assess whether, and how, a mission like DART could be used in the future to help protect Earth from a collision with



In one of the last few images sent minutes before DART's impact, the larger Didymos sits in the foreground at left, while the spacecraft's target, the moonlet Dimorphos, lies in the distance (above). NASA/JOHNS HOPKINS APL



The SOFIA airborne infrared observatory made its final flight in September 2022. NASA/JIM ROSS

Farther from home, another mission was wrapping up. Since late 2018, NASA's InSight lander had listened for marsquakes, which reveal details about the Red Planet's interior. InSight also sent back regular weather reports, shared the sounds of martian wind, and both heard and felt small space rocks fall through the thin atmosphere and strike the ground.

But survival on Mars is tough, and InSight's power levels dropped as dust coated its solar panels. In April 2022, NASA said the mission would run through the end of the year "unless the spacecraft's electrical power allows for longer operations."

In late May, the lander stopped using its robotic arm. At that time, the team reported InSight's solar panels were producing just one-tenth the power as when first deployed. By June, all instruments had been turned off — except the seismometer, which kept running about half the time instead of round the clock, says InSight Principal Investigator Bruce Banerdt.

Eventually, power levels will completely dry up and InSight will shut down. In late September, Banerdt noted that Mars' dusty season was ramping up. He estimated the mission would end due to lack of power by January 2023.

But with data on more than 1,300 marsquakes and years of meteorological and acoustic information safely sent home, Banerdt says InSight's contributions to science will continue for decades to come. "InSight's legacy is pretty substantial. We've done the things that we went to Mars to do." It took the first measurements of the thickness of the martian crust, determined the size and density of Mars' core, and gleaned details of the structure and composition of the mantle. "It's literally rewriting the textbooks on Mars," he says.

When Insight does go quiet, "It's gonna be a sad but proud moment," says Banerdt. "But I think that the plucky little lander has actually earned a rest. It's been working hard for us for a long time and I think it's earned its retirement."

an asteroid if we ever discover one headed our way," said NASA planetary science division director Lori Glaze in a press release.

Long after DART had smashed to smithereens, its target stayed in the spotlight. Images from ground- and space-based telescopes showed Dimorphos sporting first one, then two cometlike tails of dust and debris from the impact. One stretched at least 6,000 miles (10,000 km) long and persisted for more than a month. Watching their evolution has revealed details about Dimorphos' composition and structure. Astronomers will continue to follow both asteroids through March, when celestial geometry renders them unobservable for a time. And a future European Space Agency mission, Hera, will visit the pair after launching in late 2024.

It may be difficult to move mountains, but NASA has showed that at least we can move small asteroids.

STORIES TO WATCH FOR IN 2023

- The Indian Space Research Organisation expects to launch the Chandrayaan-3 lunar lander and the Aditya-L1 solar observatory in early 2023.
- ESA plans to launch the JUpiter ICy moons Explorer (JUICE) between April 5 and 25, 2023. *(TOP)*
- The ESA's BepiColombo mission will make its next Mercury flyby June 20, 2023. *(MIDDLE)*
- In June 2022, NASA delayed the planned launch of its Psyche mission to the asteroid of the same name. The next launch windows open in July and September 2023.
- NASA's OSIRIS-REx will deliver its sample of asteroid 101955 Bennu to Earth Sept. 24, 2023. *(BOTTOM)*

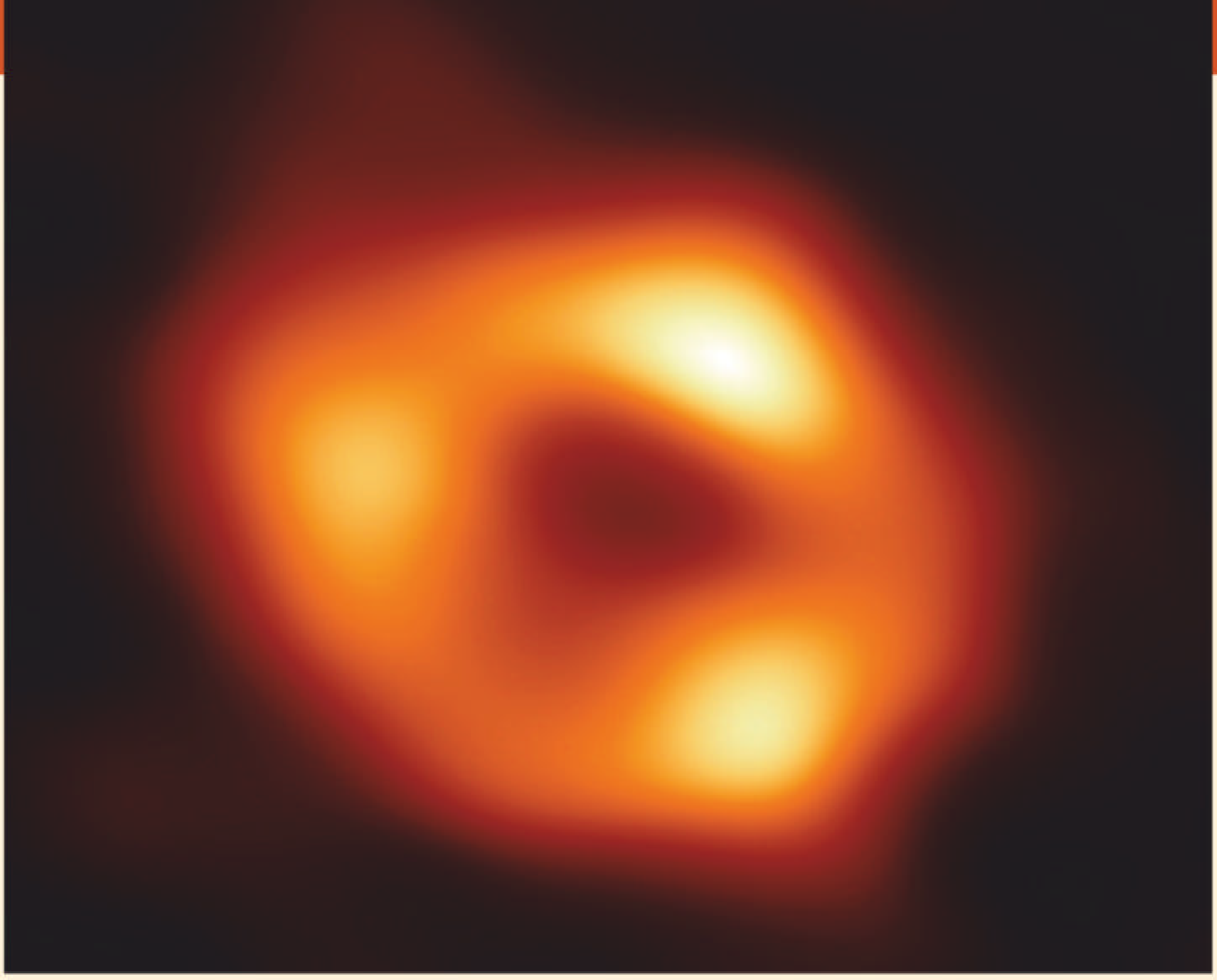
TOP TO BOTTOM: SPACECRAFT: ESA/ATG MEDIALAB, JUPITER: NASA/ESA/J. NICHOLS (UNIVERSITY OF LEICESTER); ESA/ATG MEDIALAB; UNIVERSITY OF ARIZONA/NASA GODDARD SPACE FLIGHT CENTER

2

EHT images Milky Way's monster black hole

IN 2019, THE EVENT HORIZON TELESCOPE (EHT) released its groundbreaking first image of a black hole 55 million light-years away in the galaxy M87. Ever since, the world had been eagerly awaiting a glimpse of the monster lurking at the center of our own Milky Way.

In 2022, we finally got it: On May 12, the EHT presented the first portrait of Sagittarius A* (abbreviated Sgr A*), a 4-million-solar-mass behemoth just 27,000 light-years away. Like the previous picture, it shows the shadow of the black hole's event horizon, or point of no return, silhouetted against the bright plasma in its accretion disk. Some of the light in the glowing ring comes from behind the black hole, bent around it by gravity.



The long-awaited EHT image of Sagittarius A*, the black hole in the center of the Milky Way, shows the dark shadow of its event horizon silhouetted against a bright ring of plasma. Some of the light in this image comes from behind the black hole and has been bent toward us by Sagittarius A*'s immense gravity. EHT COLLABORATION

The image, created by observing the galactic center with a worldwide network of eight radio telescope arrays over several days and combining the results, is vital in many ways. Although astronomers had long surmised Sgr A* was a black hole, all evidence to this point had been secondhand. Scientists watched stars at the galactic center orbit a massive, invisible object and measured the radiation it released as it consumed material. The image, however, is direct evidence of Sgr A*'s nature.

But why did M87's image come first? General relativity states that all black holes should look essentially the same. It also says the size of a black hole's event horizon (and thus shadow) scales linearly with mass. A more massive black hole has a larger event horizon and its accretion disk sits farther out. At the same speed, orbiting material takes longer to circle a more massive black hole than a less massive one.

"The images that we're making are not of the event horizon itself, but of high-energy electrons, this sort of super plasma, that's swirling in this gravitational

1

The era of JWST begins

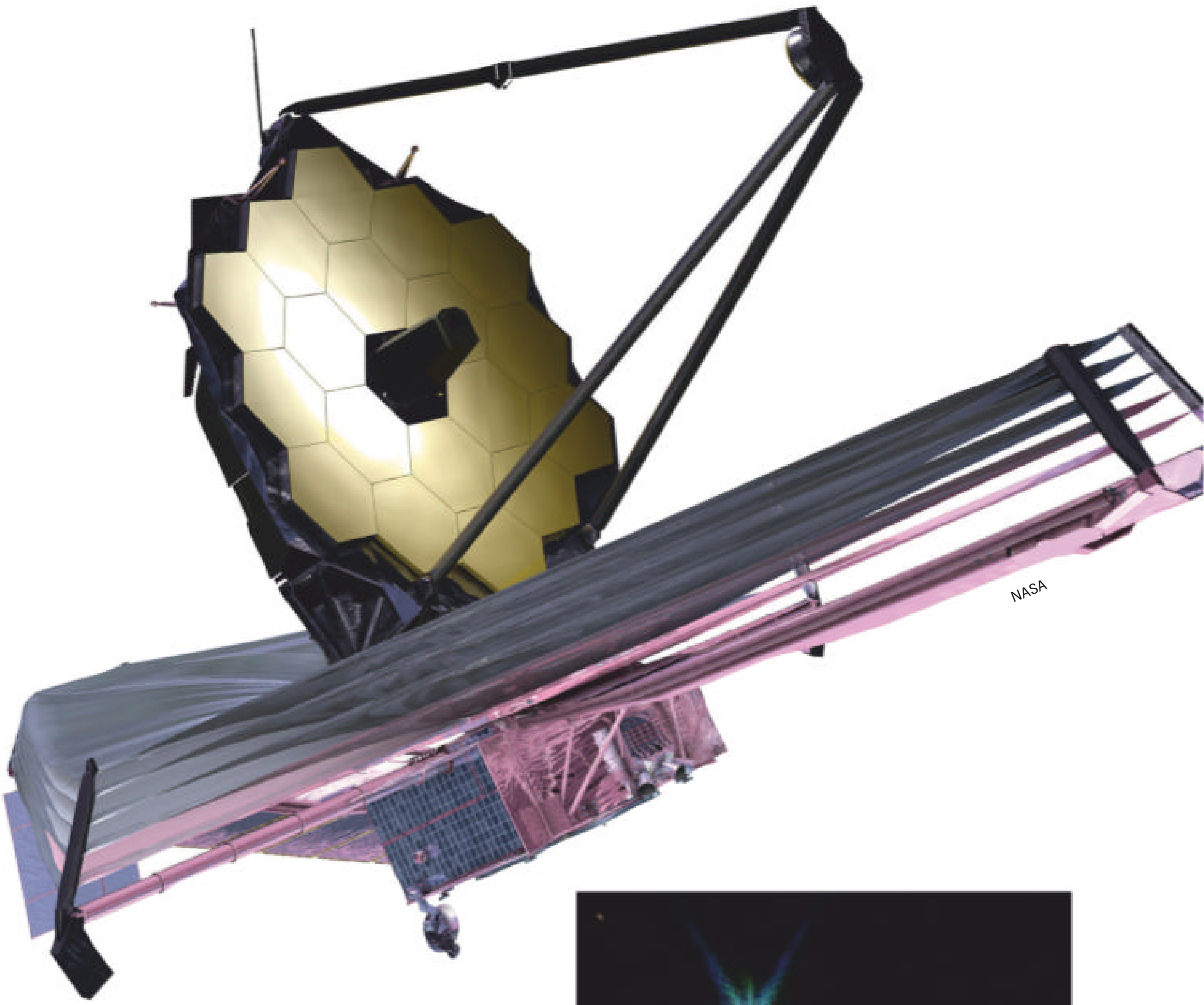
THE TOP SCIENCE STORY of 2022 is a tale more than two decades in the making. First considered in 1989 and formally recommended in 1996, NASA began construction of an infrared space telescope in 2004. Seventeen years later, at 7:20 A.M. EST on Dec. 25, 2021, the James Webb Space Telescope (JWST) launched from Kourou, French Guiana, aboard an Ariane 5 rocket.

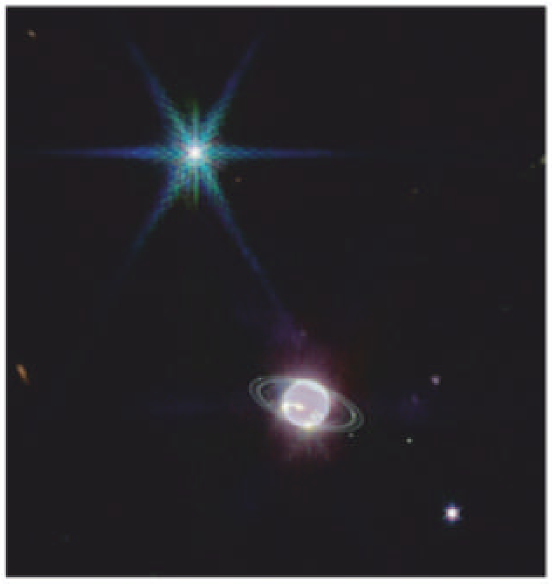
The astronomical community rejoiced. But there was still much to do. As the telescope traveled to its destination at the L2 Lagrange point of Earth's orbit, some 930,000 miles (1.5 million km) away, it began an intricate dance. The steps involved unfolding and locking its 6.5-meter mirror and tennis court-sized sunshield, both carefully stowed to fit inside the rocket fairing that carried it into space. If any step failed, there was no way to reach and repair the telescope.

The very first publicly released JWST image shows a deep infrared view of the galaxy cluster SMACS 0723. NASA, ESA, CSA, STSCI maelstrom about the event horizon," says Nicholas MacDonald at the Max Planck Institute for Radio Astronomy in Bonn, Germany, the European outreach coordinator for EHT. "The characteristic timescale in M87* [M87's black hole] is months to days that it takes for stuff to swirl around, and in contrast, in Sgr A*, because it's such a smaller physical structure, that timescale is days to minutes." So, Sgr A* was blurring itself out even as astronomers observed it, requiring two years of complex and careful processing to produce the final image.

Such images, MacDonald stresses, rely on a huge collaboration of hundreds of people working together. "You can't do it unless you have these telescopes around the world," he says.

For now, these are the only supermassive black holes EHT can image so closely, due to their size on the sky. But EHT is far from done. Next, "the EHT very much wants to make movies" of the orbiting plasma, says MacDonald, by observing both black holes multiple times a year. That will let us watch these monster black holes change with time on the smallest possible scale, something never before seen. "It's a really fun time to be in this business," he says.


NASA


JWST's first look at Neptune captured the clearest view of the planet's rings in decades.
NASA, ESA, CSA, STSCI, IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

"Every piece of this huge, gorgeous observatory was ingeniously designed, custom made, mostly by hand, and torture-chamber tested and re-tested," wrote Jane Rigby, JWST operations project scientist at NASA's Goddard Space Flight Center, in a blog the day of launch. "So many hands cradled this bird. So many brains dreamed up science observations. So many worked so hard — now we see if it works."

It did. By Jan. 4, 2022, the sunshield had fully deployed. The next day, the scope's secondary mirror was in place, and by Jan. 8, the primary mirror had unfolded. On Jan. 24, JWST arrived at L2. Then came months of cooling the telescope's optics, aligning its mirror segments, and turning on and checking its four instruments. Initial test images showed tantalizing hints of target stars and even background galaxies in exquisite detail.

Finally, NASA announced it would publicly release the telescope's first images July 12. But U.S. President Joe Biden surprised the world one day early, on July 11, by presenting the deepest, sharpest infrared image ever taken, showing the distant galaxy cluster SMACS 0723. The next day, the JWST team released four additional groundbreaking images: the Southern Ring planetary nebula, Stephan's Quintet of galaxies, the star-forming region NGC 3324 in the Carina Nebula, and the spectrum of the gas giant exoplanet WASP-96 b. Each showed a new view of our universe, from potential water and haze in an exoplanetary atmosphere to forming stars amid galactic dust and gas.

Since then, new photos and discoveries have come at a rapid pace — some as official press releases, others shared by researchers eager to show how JWST is already revolutionizing science. Targets have included solar system planets like Jupiter (see page 36) and Neptune, as well as distant objects such as the earliest known star, Earendel. In early September, JWST directly imaged its first exoplanet, a gas giant several times Jupiter's mass.

The telescope is off to an auspicious start. And it is only the start. JWST has enough propellant to continue doing science for over a decade — more than twice its minimum mission lifetime of five years. Throughout commissioning, the team repeatedly reported its optics were performing above baseline benchmarks. In a nutshell, JWST is performing better than expected and has the capability to do so for more than a decade.

"Our immense golden telescope is seeing where none have seen before, discovering what we never knew before, and we are proud of what we have done," said JWST senior project scientist John Mather in a NASA interview. "Webb was worth the wait!"

Alison Klesman *is senior editor of* Astronomy*, and can't wait to see where 2023 will take us.*

SEE WINTER'S BEST

Messier objects

Bundle up and behold the season's finest deep-sky targets.

BY MICHAEL E. BAKICH

As backyard observers may know, some modest telescopes lack the optics or aperture to cleanly resolve deep-sky objects like nebulae, star clusters, and galaxies. This leads to fuzzy images, often making it difficult to characterize exactly what you're looking at. That's why French comet-hunter Charles Messier documented 109 deep-sky objects that, through his small scope, appeared to be masquerading as comets, despite the fact they didn't move against the starry background sky.

A brief window exists from mid-March to early April when observers in the Northern Hemisphere can catch all of Messier's objects, which are unevenly spread across the sky, in a single night. This feat is called a Messier marathon, and astronomy clubs around the world have been hosting events to celebrate the celestial race since the 1980s.

But what if you can't devote a whole night to the hunt? Then you should try running a Messier mini-marathon, where you target a subset of Messier objects between the end of twilight and midnight. So far, I've done Messier mini-marathons for spring (April 2021 issue), summer (August 2021), and autumn (October 2022). Here's the fourth: Winter is coming.

To carry out this mini-marathon, begin with the first object on the list. It resides farthest west, so the following objects will set one after another, in order, saving you search time.

In 2023, the Moon is New on Jan. 21 and Feb. 20, so your first observing window runs from around Jan. 14 to Jan. 23. After that, moonlight will interfere with your search until Last Quarter, which occurs Feb. 13. Then the sky will stay Moon-free until after midnight each night for another week, marking your second observing window.

So set up your scope, kick back, and enjoy the last of the mini-marathons!

Under the sky

We'll start with globular cluster **M79** in Lepus, which lies south of Orion. To spot M79 — the most southerly Messier object in the winter sky — draw a line from Alpha (α) through Beta (β) Leporis and extend it just slightly more than the distance between those two stars. For all of its magnitude 7.8 brightness, M79 is difficult to resolve through small scopes. A 10-inch instrument shows that the 8.7'-wide globular has a bright, broad core. But crank up the magnification beyond 200x, and you'll resolve scores of stars at the cluster's edges.

Next up is **M78** in Orion. Although it's the sky's brightest reflection nebula (magnitude 8.3), you'll still need a dark site to see it well. Through a 4-inch scope at about 120x, you'll spot an 11th-magnitude star with the two densest parts of M78 on either side of it. The nebula measures 8' by 6' and lies in a region with only a few background stars.

Our third target is barred spiral galaxy **M95** in Leo. It glows at magnitude 9.7 and spans 7.8' by 4.6'. You'll find it 3.6° northeast of Rho (ρ) Leonis. Through an 8-inch scope, M95 appears slightly elongated in a north-northeast to south-southwest orientation. The small core has a faint outer ring that marks the brightest parts of M95's arms. You'll see the bar through a 16-inch or larger scope at high power. It stretches from one side of the ring to the other.

Spiral galaxy **M96** travels through space with M95 and lies just 0.7° west of it. At magnitude 9.2, this is one of the sky's brightest galaxies. Through a 4-inch scope, you'll see a bright, evenly illuminated oval (4' by 3') stretching northwest to southeast. There's not much detail to see here, except for a slightly brighter tiny core.

You won't need to move your scope much for elliptical galaxy **M105**, which lies only 0.8° north-northeast of M96. It glows at magnitude 9.3 and has a diameter of 3.9'. M105 has a bright central region surrounded by a halo with an edge that's difficult to define.

Our next target is barred spiral **M108** in Ursa Major. It glows at magnitude 10.0. Although not exactly a galactic "needle," it is four times as long as it is wide (8.1' by 2.1'), tilting east-northeastward. Look for it 1.5° east of Merak (Beta Ursae Majoris). Oh, and don't be fooled by the 12th-magnitude star that lies between us and M108's core: It's not a supernova.

Now move to Leo and draw a line from Chertan (Theta [θ] Leonis) to Iota (ι) Leonis. At its midpoint, you'll find the terrific spiral **M65**. This galaxy belongs to the Leo Triplet — a triangular group that fits into a field of view 0.6° across. The other members are M66 and NGC 3628. M95 measures 8.7' by 2.2' and glows at magnitude 9.3. Look carefully to see some mottling north and south of the galaxy's broad core.

From M65, move only 0.3° east-southeast to find an even brighter celestial wonder, spiral **M66**. Glowing at magnitude 8.9, it looks a bit hazy, although it has a well-defined edge. It's twice as long as it is wide (8.2' by 3.9') and stretches north to south. The bright core really stands out, but you'll need a 12-inch scope at 200x to see even a hint of the spiral arms.

Next, head back to Ursa Major for barred spiral **M109**. This galaxy glows at magnitude 9.8 and measures 7.6' by 4.3'. To find it, first center Phecda (Gamma [γ] Ursae Majoris) in your telescope. Then move 0.6° to the east-southeast. Although M109 has a low surface brightness, an 8-inch scope under superb conditions will reveal the bar. I recommend

So set up your scope, kick back, and enjoy the last of the mini-marathons!

OPPOSITE: Some 40,000 light-years distant, M79 is a sparkling blizzard in the constellation Lepus. Within its borders are some of the oldest stars in our galaxy. NASA AND ESA; ACKNOWLEDGEMENT: S. DJORGOVSKI (CALTECH) AND F. FERRARO (UNIVERSITY OF BOLOGNA)

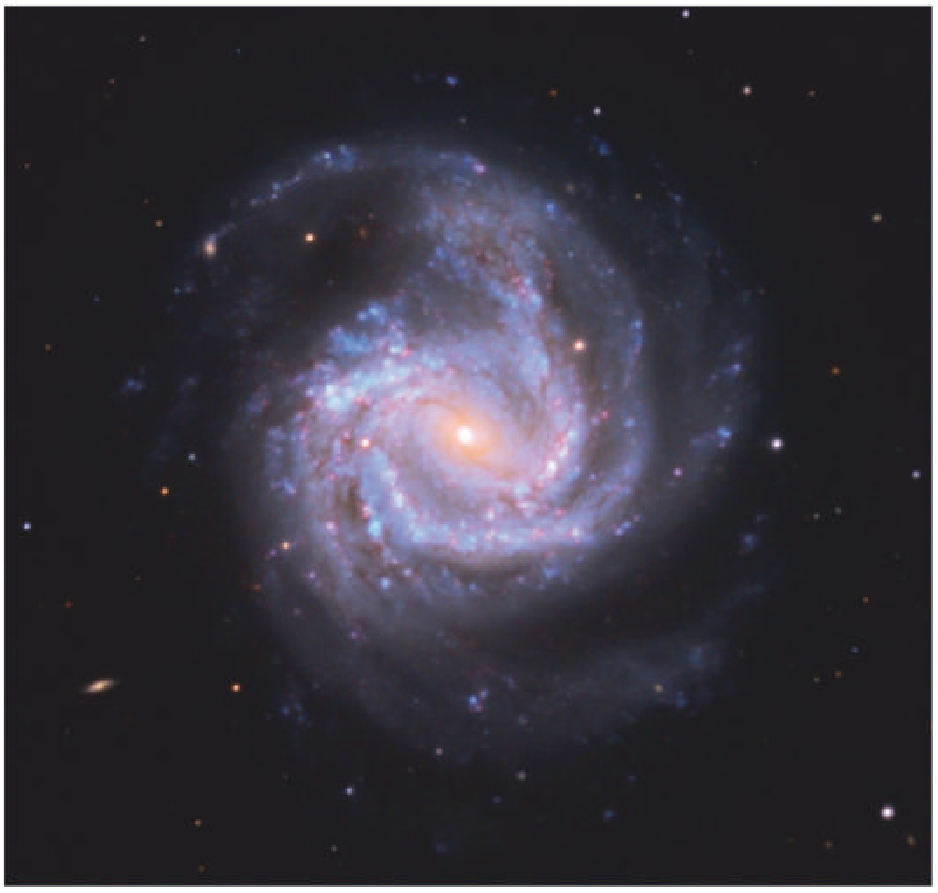
ABOVE: Two stars, HD 38563 A and HD 38563 B, light up a hazy patch of dark gas for observers, forming the reflection nebula M78. ALAN DYER

CENTER: While the unrelated stars that make up M40 aren't the most exciting object on this list, it's still worth your time. NOIRLAB/NSF/AURA using magnification of 200x or greater.

Our next two targets, **M98** (magnitude 10.1) and M99 (magnitude 9.9), are both spiral galaxies and lie in Coma Berenices. The easiest way to find them is to head 7.2° east of Denebola (Beta Leonis), where you'll find M98. From there it's just a short jump 1.3° east-southeast to reach M99. Through an 8-inch scope at 200x, M98 appears as a fat spindle nearly four times as long as it is wide (9.5' by 2.5'). The core is broad and slightly brighter than the arms.

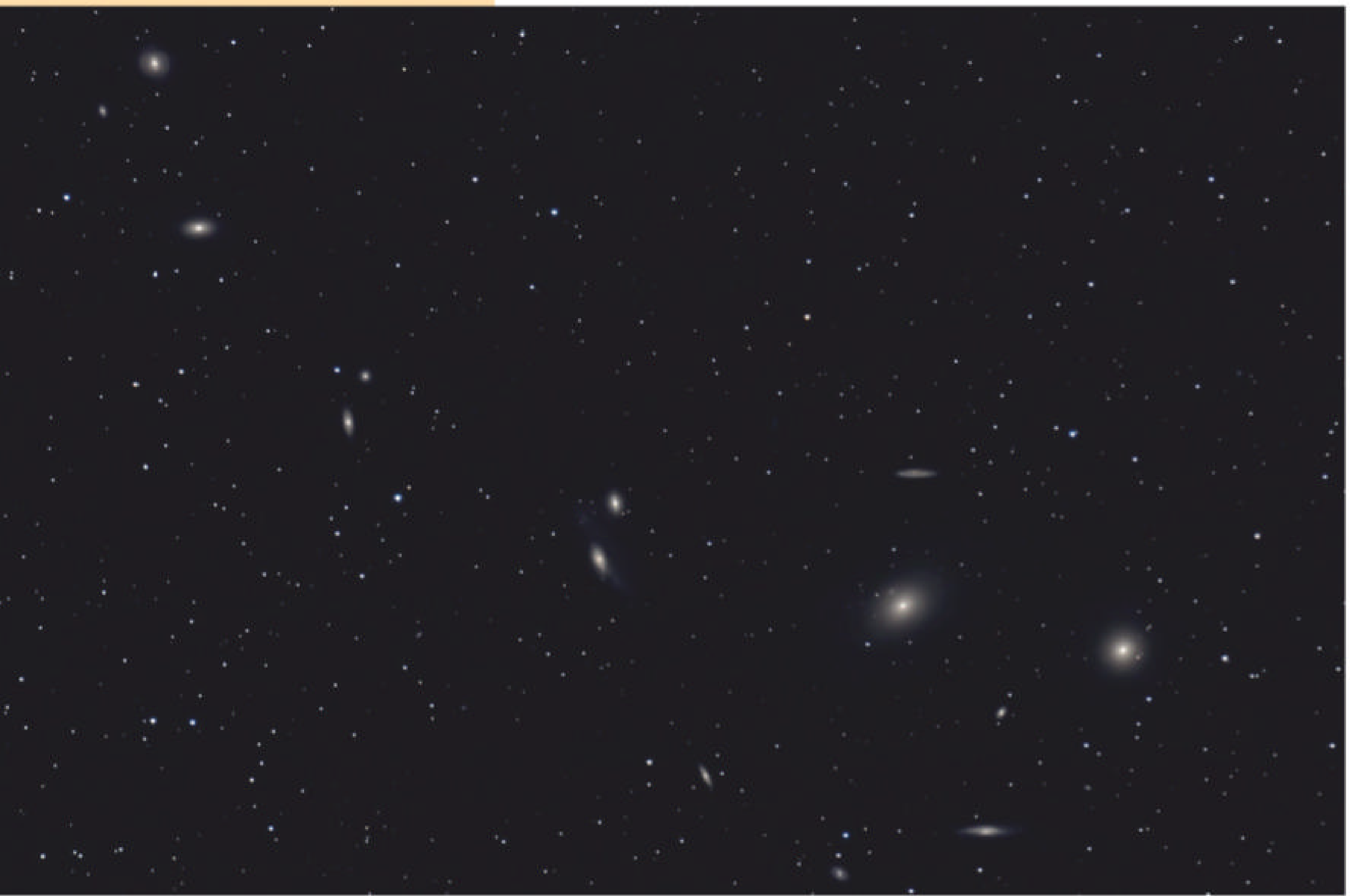
M99 appears nearly circular (5.2' by 4.6'), but it looks weird. In fact, even through a 10-inch scope, M99 appears to have only one spiral arm, which winds under the face-on galaxy's southern edge. This arm appears brighter than the other because it's full of large star-forming regions, which you'll recognize as the bright clumpy areas.

Now we move to the small constellation Canes Venatici for spiral **M106**. This great target glows at magnitude 8.4 and measures 20' by 8'. M106 has a tilt to our line of sight similar to the Andromeda Galaxy (M31), so the features the two galaxies showcase share a resemblance. M106 makes a triangle with Chi (χ) Ursae Majoris and Phecda; it lies 5.5° east of Chi and 7.5° southeast of Phecda. You'll first see a bright core surrounded by an oval haze. Inside the haze is a stretched-out inner disk that's a third of the galaxy's size. Through a 10-inch or larger telescope, you'll begin to see the mottled texture and spiral structure. The strikingly linear northern arm appears more pronounced, while the southern arm looks more diffuse.



RIGHT: M61 is a prominent member of the Virgo Cluster of galaxies. If we could view the Milky Way face-on, it would likely look similar to this spiral. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

BELOW: This string of galaxies is known as Markarian's Chain (NGC 4374). M84 sits to the very right, followed by M86 to its immediate left. ALAN DYER



To find our next target, spiral galaxy **M61**, first locate the stars 16 and 17 Virginis. Their magnitudes are 5.0 and 6.5, respectively. M61 lies between them, just a bit closer to 17 Vir. It glows at magnitude 9.7 and measures 6.0' by 5.5'. M61's arms wind tightly around its core. Through a 12-inch scope, you'll see their stubby extensions.

At magnitude 9.3, spiral **M100** in Coma Berenices ranks as one of the brightest galaxies in the Coma-Virgo cluster, and it's a great target for amateur telescopes. It lies 8.3° east of Denebola, or 1.9° east-northeast of the magnitude 5.1 star 6 Comae Berenices. The galaxy measures 6.2' by 5.6'. Through an 8-inch scope, you won't see M100's arms until you crank the magnification up above 200x, and then you'll still only get good views on the best nights. The arms appear as brighter regions east and west of the nucleus.

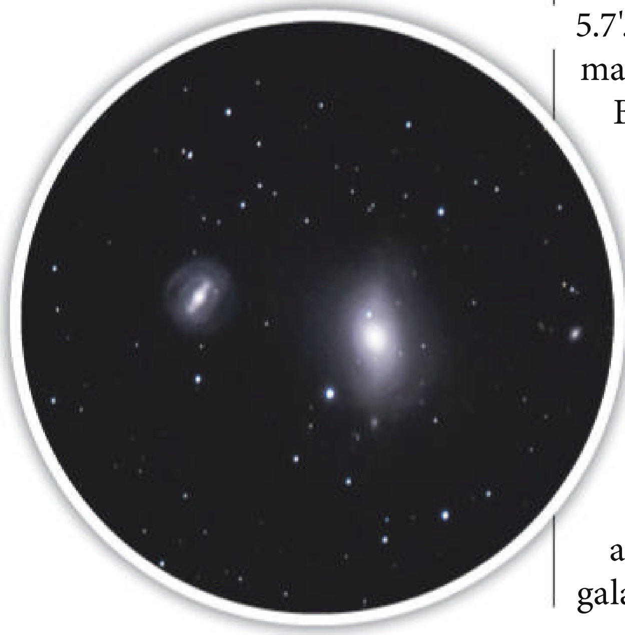
While the inclusion of **M40**, also known as Winnecke 4, may seem to merit an apology, this clunker is indeed an entry in Messier's catalog — though perhaps the oddest one. This object is a widely spaced optical double star in Ursa Major, 1.4° northeast of Megrez (Delta [δ] Ursae Majoris). The components glow at magnitudes 9.0 and 9.6, and their separation is nearly an arcminute (53"). The primary appears light yellow, while the secondary is a deep yellow, although many observers see it as pale orange. Despite its relatively dull nature, M40 deserves at least a quick look.

It's easy to confuse **M84** with nearby M86. Both are ellipticals in Virgo that lie

ABOVE LEFT: The spiral galaxy M109 is the most distant Messier object, at 83.5 million light-years. ALAN DYER

ABOVE: M95 (bottom right) and M96 (bottom center) are interstellar travel companions. M105 (upper left) lies just a short distance away. This trio of galaxies also includes NGC 3389 (left) and NGC 3384 (right). ALAN DYER/AMAZINGSKY.COM

LEFT: X-rays from the elliptical galaxy M49 indicate that a supermassive black hole weighing some 565 million solar masses lies at its heart. ALAN DYER



BELOW LEFT: M85 is an example of a lenticular galaxy, an intermediate category between spirals and ellipticals in galactic morphology. ALAN DYER

midway between Denebola and Vindemiatrix (Epsilon [ε] Virginis), but M84 lies a bit more westerly. Also, M84 is smaller (5.1' by 4.1') and slightly fainter (magnitude 9.1). Its core is large and decidedly nonstellar, so watch for a faint halo that surrounds it.

And while you're in the area, go ahead and observe **M86**, which lies only 0.3 from M84. It glows at magnitude 8.9 and measures 12' by 9.3'. Even low-power eyepieces reveal this galaxy's oval shape, so it's more a lenticular than a spiral, although it's still classified as the latter. Unlike many ellipticals, however, M86 has a tiny starlike core. High magnifications bring it out best.

Lenticular galaxy **M85** in Coma Berenices looks like an edge-on spiral, but it doesn't have a spiral galaxy's arm structure. It glows at magnitude 9.1 and measures 7.5' by 5.7'. To find it, first locate the magnitude 4.7 star 11 Comae Berenices. From there, head 1.2° east-northeast, and M85 will be in your field of view. A small scope shows a bright core surrounded by an oval halo. Through a 12-inch or larger instrument you'll see this brightness difference as you move out from the galaxy's center. You may also detect a subtle yellow color. That's because this galaxy contains vast numbers of old yellow stars.

Next up is **M49** in Virgo. This elliptical galaxy, located some 8.5° southwest of Vindemiatrix, glows relatively brightly at magnitude 8.4. It appears slightly oval, measuring 8.1' by 7.1'. The core makes up the central two-thirds of this object, and a fainter outer region envelops it. If your seeing (a measure of the steadiness of the air) is good, crank up the power and look for M49's outer halo.

Our final target, elliptical galaxy **M87** in Virgo, is a colossal object, with a mass in excess of 3 trillion Suns and a diameter that may reach half a million light-years. It also has nearly 100 times as many globular clusters as the Milky Way. All that said, however, it probably won't wow most observers. It glows at magnitude 8.6 and has an apparent diameter of 7.1'. The one feature you'll definitely notice is its bright core, which spans about one-third of the galaxy's overall size.

Practice patience

Spending time with each of these deep-sky wonders will pay dividends in the amount of detail you'll see. Don't worry about rushing out right away on a subpar night. Many of the objects on this list will linger high in the sky throughout most of the spring. And remember, the only rule for any marathon, mini or full, is to have fun!

Michael E. Bakich *is a contributing editor of* Astronomy *who has seen even M40 dozens of times.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

FEBRUARY 2022

In January 2020, Venus (center) passed within about 15' of Neptune (blue dot to Venus' lower right). This month, the two make another approach, nearly as close. ALAN DYER

Venus moves along

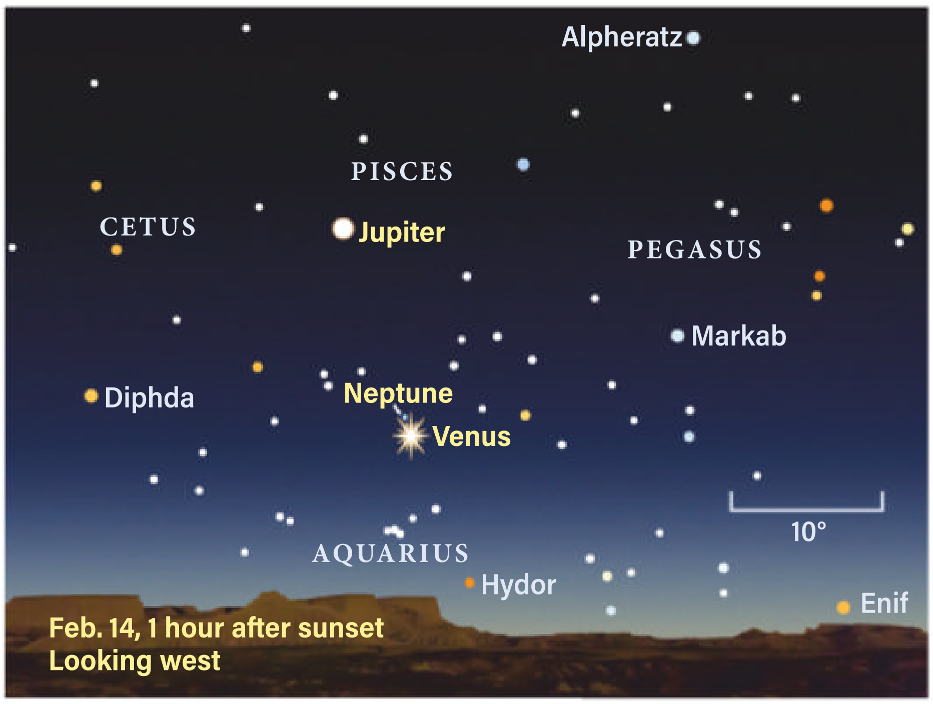
Three bright planets are visible every evening in February, and two more can be spotted with binoculars. Venus, Jupiter, and Mars are strung across the western sky after sunset; the first two set earlier, while Mars remains long into the night. The scene is perfect for planetary observers with telescopes, offering plenty of features to enjoy. After Mars sets in the early hours after midnight, you'll have to wait until the predawn hour to spot Mercury — catch it in the first week of the month for the best views, as it's just past its greatest elongation from the Sun.

We begin with Venus and Jupiter, shining brilliantly in the southwestern sky this month. Standing nearly 29° apart on Feb. 1, watch each evening as Venus climbs upward and Jupiter descends until they almost meet on Feb. 28.

Venus is the brighter of the two at magnitude –3.9 all month. On Feb. 1, Venus sets two hours after the Sun. This places it 10° high in a dark sky an hour after sunset. A telescope reveals an 11"-wide disk that is 91 percent lit. As you follow Venus climbing through the month, its disk grows slightly to 12" and the phase shrinks to 86 percent.

Wandering against the faint stars of Aquarius early in the month, Venus reaches the area of sky containing the much more distant **Neptune**. On Feb. 14, the pair stand some 33' apart, the equivalent width of the Full Moon. Neptune is comparatively quite dim at magnitude 7.8. Binoculars will reveal it if the sky is dark enough and very clear near the horizon. Neptune stands northeast of Venus. Note two brighter 7th-magnitude stars west of Venus. If you can see these stars easily, Neptune will be within reach.

Dance partners



Feb. 14, 1 hour after sunset
Looking west

In mid-February, bright Venus closes in on Neptune. You'll need at least binoculars to see the distant ice giant. By Feb. 15, Venus and Neptune have switched places compared to this chart. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

The following evening, Feb. 15, the planets' positions are switched as Venus, closer to Earth, has moved 40' northeast of Neptune's location and crossed into Pisces. As you view the pair of planets, consider that Venus is only 1.4 astronomical units (AU) away, while Neptune is a staggering 30.8 AU distant. (One AU is the average Earth-

OBSERVING HIGHLIGHT

VENUS passes close to **NEPTUNE** on Feb. 14 and 15, first sitting southwest and then northeast of the ice giant.

Sun distance.) Through a telescope, Neptune's disk spans 2" — near the resolution limit of small scopes — and its appearance will be strongly affected by the low altitude.

During the last half of February, Venus closes the remaining 14° gap to Jupiter. Jupiter stands in Cetus, crossing into Pisces on the 19th. On Feb. 21 and 22, a thin crescent Moon joins the pair of bright planets. On the 21st, Luna hangs 6° below Venus; the following

— Continued on page 34

RISING MOON | Flooded and floodlit

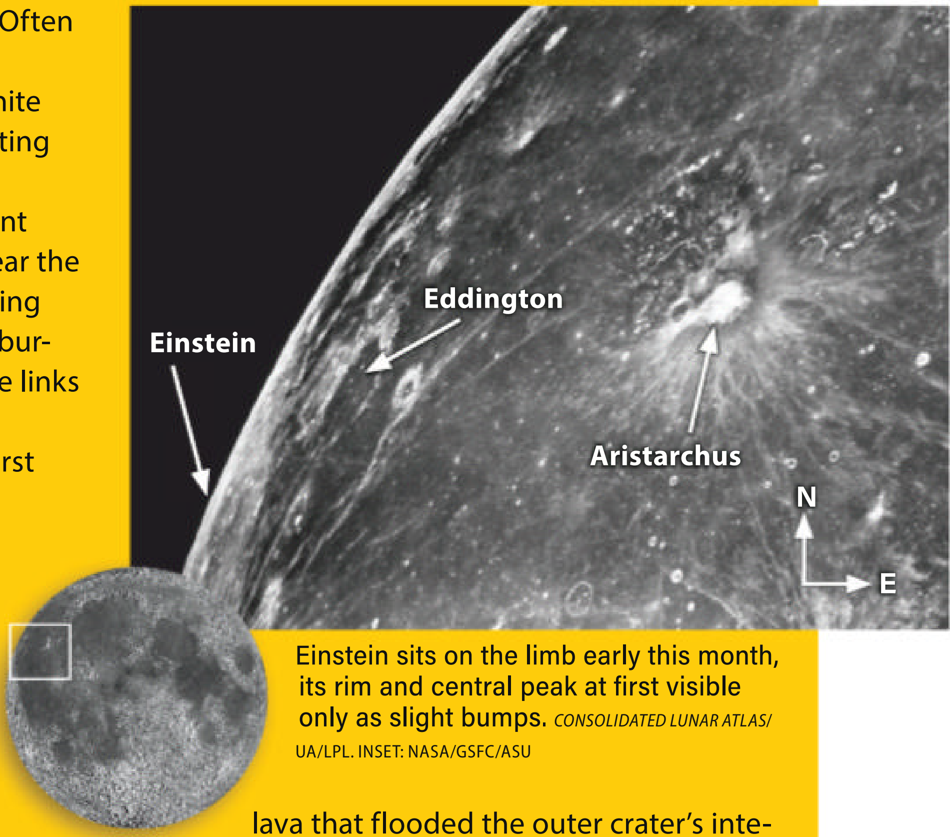
THANKS TO ORBITAL good timing, we can saunter along the distant shoreline of the giant Ocean of Storms in the Moon's northwest. Often it is tilted out of view or only visible after a midnight moonrise, but this month, the white highlands are visible for a whole week starting at Full Moon.

On the evening of the 4th, the prominent horseshoe-shaped crater Eddington lies near the day-night terminator line, due west of blazing Aristarchus. Eddington's southern half lies buried under a sea of lava. A neat wrinkle ridge links two nearby sharp-edged craters.

Sunday evening (the 5th) gives us our first view of Einstein, west and a little south of Eddington. Slightly bigger, a respectable 125 miles across, Einstein is a battered ring with a secondary crater in its middle. But it won't look like a typical crater this night because it lies edge-on to our line of sight. Look right on the limb for three bumps, which are a profile of the crater rim with its central peak. The outer two high spots are a bit farther apart than Eddington's width.

With each successive night, the Moon's western limb appears to roll slightly toward us, transforming the view from edge-on to a shallow angle, so that by the 9th, Einstein's inner crater is noticeable, surrounded by some darker lava that flooded the outer crater's interior. Use a filter to cut the glare, such as a cross-polarized pair that will allow you to dial in the amount of reduction. Alternatively, a deep-blue filter, sunglasses, or increasing the magnification are good ways of managing the light. The sequence nearly repeats next month, starting March 5th.

Aristarchus, Einstein, and Eddington



Einstein sits on the limb early this month, its rim and central peak at first visible only as slight bumps. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Soft glow after sunset

Search out the zodiacal light

Similar in brightness to the Milky Way, the zodiacal light appears in the west after winter sunsets. MIKE LEWINSKI

METEORS ARE FEW and far between during February, with no major showers. A minor background rate of a handful of meteors per hour is visible nightly. On Feb. 11, about a week after the Moon passes Full, look toward the western horizon for the zodiacal light. This cone-shaped glow is aligned with the ecliptic and is noticeable if you cast your eyes to and fro along the horizon. The light is sunlight reflecting off solar system debris left by ancient comets.

Pick a countryside observing location where the western horizon is very dark, absent of any streetlights near or far. An hour or so after sunset, the zodiacal light becomes visible. It lasts more than an hour, slowly setting as the evening progresses. You can increase your chances of seeing the zodiacal light by gaining elevation. This glow is a regular occurrence from any mountain vantage point with a view to the west.

STAR DOME

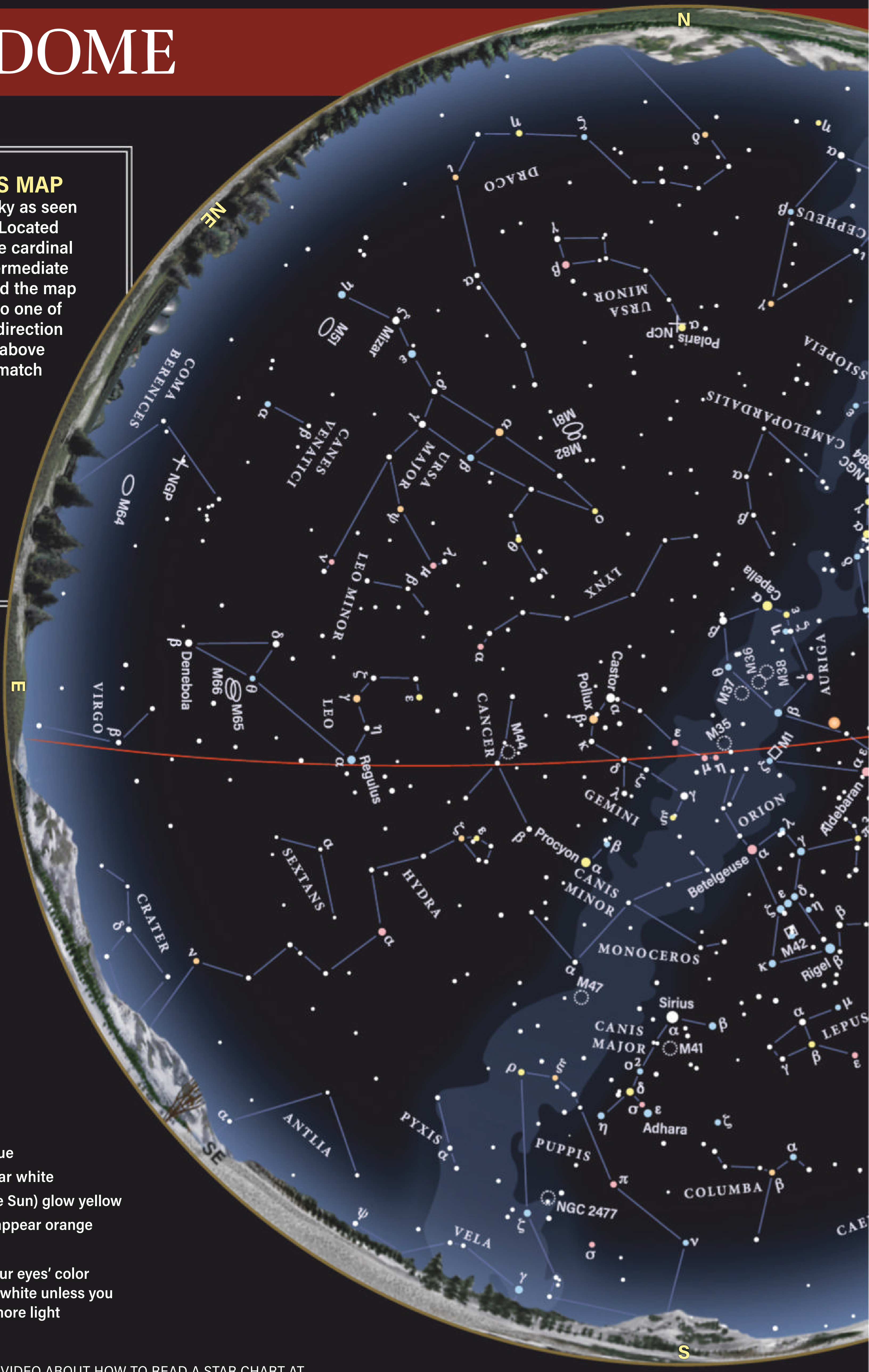
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. February 1
9 P.M. February 15
8 P.M. February 28

Planets are shown at midmonth



N
NE
E
SE
S
DRACO
URSA MINOR
Polaris
NCP
CEPHEUS
CASSIOPEIA
CAMELOPARDALIS
NGC
URSA MAJOR
M81
M82
Mizar
M51
CANES VENATICI
COMA BERENICES
NGP
M64
LEO MINOR
LYNX
Capella
AURIGA
M36
M37
M38
M35
M1
Castor
Pollux
CANCER
M44
LEO
Regulus
Denebola
M65
M66
VIRGO
GEMINI
ORION
Betelgeuse
Aldebaran
Procyon
CANIS MINOR
HYDRA
SEXTANS
CRATER
MONOCEROS
M47
M42
Rigel
Sirius
CANIS MAJOR
M41
LEPUS
Adhara
PUPPIS
PYXIS
ANTLIA
COLUMBA
NGC 2477
VELA
CAE

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

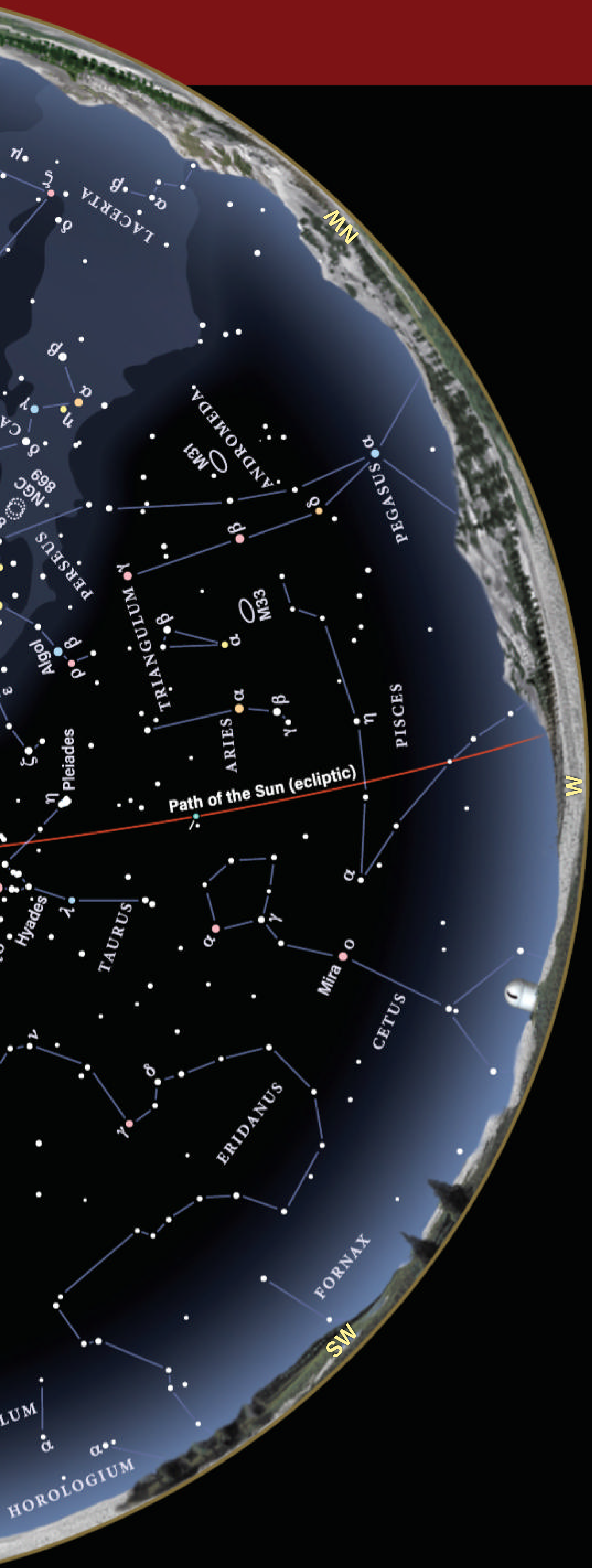
- ● Sirius
- ● 0.0
- ● 1.0
- • 2.0
- • 3.0
- • 4.0
- · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**


LACERTA
NW
ANDROMEDA
M31
NGC 869
PERSEUS
PEGASUS
TRIANGULUM
M33
Algol
ARIES
PISCES
Pleiades
Path of the Sun (ecliptic)
W
Hyades
TAURUS
Mira
CETUS
ERIDANUS
FORNAX
SW
HOROLOGIUM
LUM

FEBRUARY 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

4 The Moon is at apogee (252,573 miles from Earth), 3:55 A.M. EST

5 Mars passes 8° north of Aldebaran, 2 A.M. EST

Full Moon occurs at 1:29 P.M. EST

8 Dwarf planet Ceres is stationary, 3 P.M. EST

12 Asteroid Pallas is stationary, 3 P.M. EST

13 Last Quarter Moon occurs at 11:01 A.M. EST

15 Venus passes 0.01° south of Neptune, 7 A.M. EST

16 Saturn is in conjunction with the Sun, noon EST

18 The Moon passes 4° south of Mercury, 4 P.M. EST

19 The Moon is at perigee (222,617 miles from Earth), 4:06 A.M. EST

20 New Moon occurs at 2:06 A.M. EST

21 The Moon passes 2° south of Neptune, 1 P.M. EST

22 The Moon passes 2° south of Venus, 3 A.M. EST

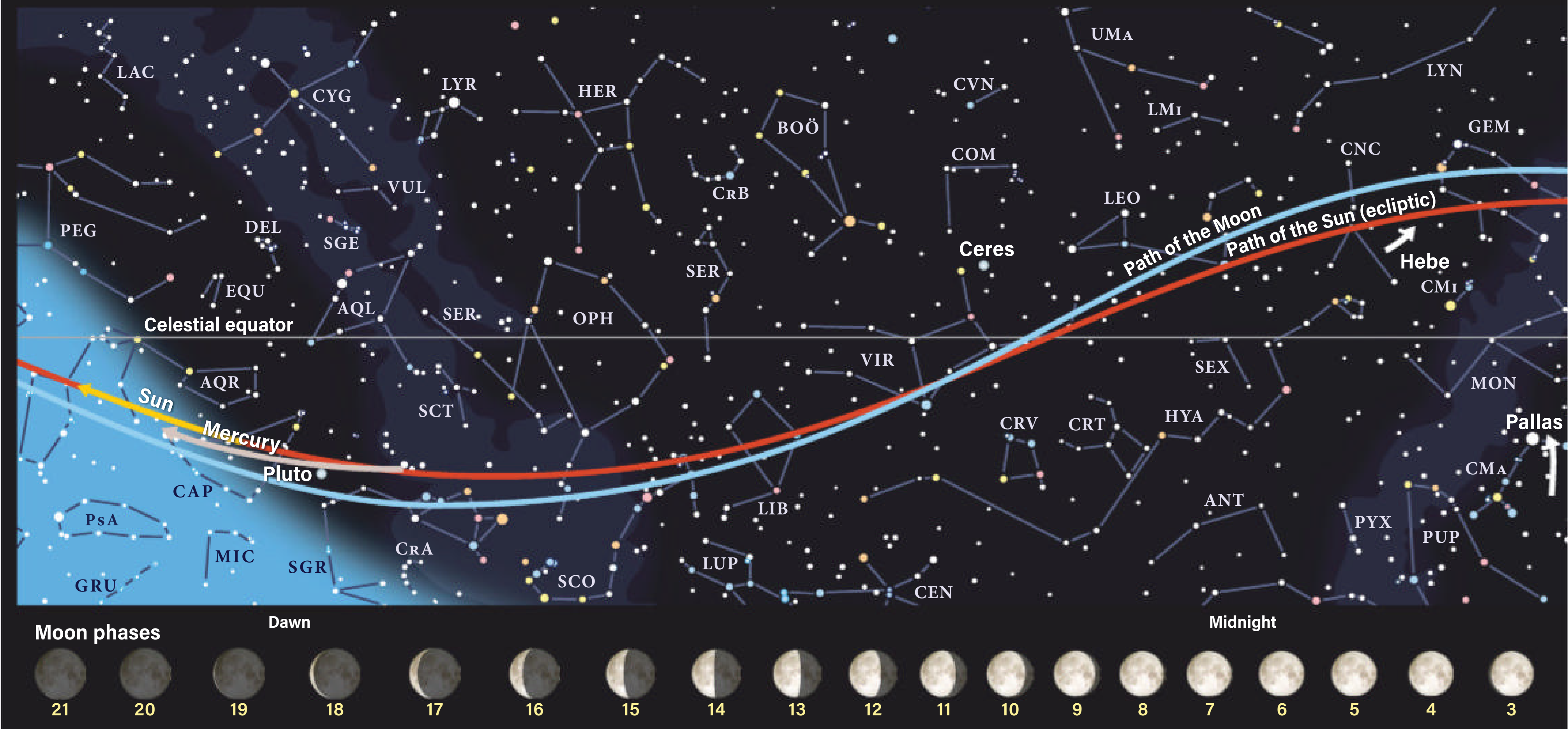
The Moon passes 1.2° south of Jupiter, 5 P.M. EST

25 The Moon passes 1.3° north of Uranus, 8 A.M. EST

27 First Quarter Moon occurs at 3:06 A.M. EST

The Moon passes 1.1° north of Mars, midnight EST

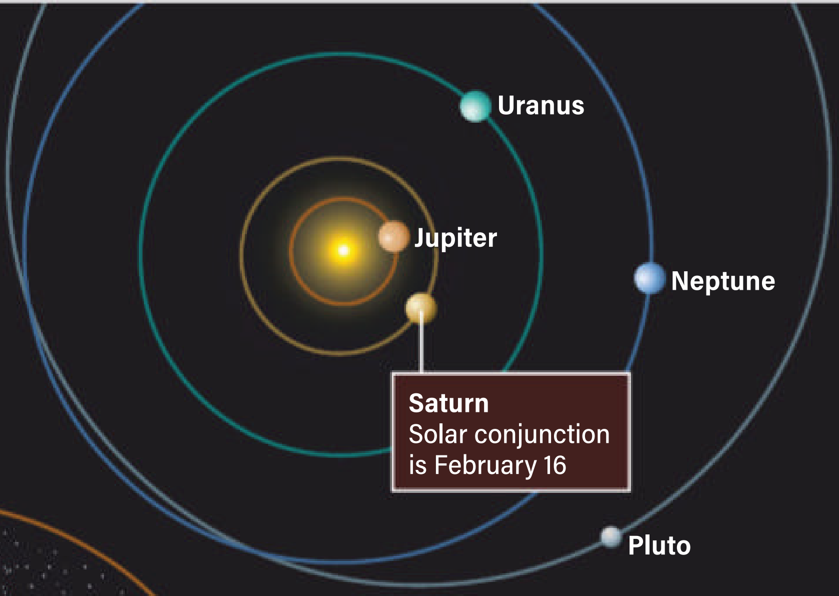
PATHS OF THE PLANETS


LAC
CYG
LYR
HER
CVN
UMA
LYN
LMI
GEM
CNC
BOÖ
COM
PEG
DEL
SGE
VUL
CRB
LEO
Ceres
Path of the Moon
Path of the Sun (ecliptic)
Hebe
CMI
SER
EQU
AQL
SER
OPH
Celestial equator
VIR
SEX
MON
AQR
Sun
SCT
CRV
CRT
HYA
Pallas
Mercury
Pluto
CMA
CAP
LIB
ANT
PSA
PYX
PUP
MIC
SGR
CRA
LUP
SCO
CEN
GRU
Moon phases
Dawn
Midnight
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3

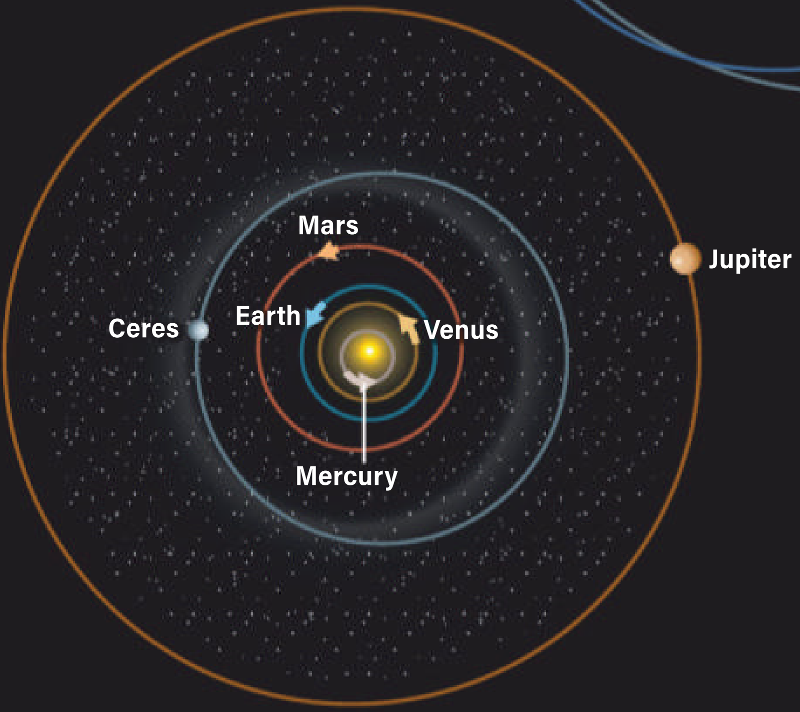
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.

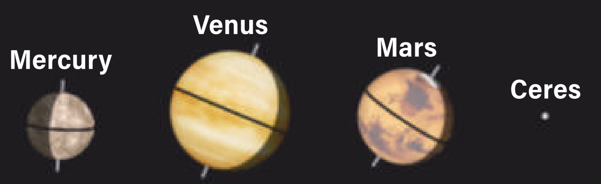

Uranus
Jupiter
Neptune
Pluto

Saturn
Solar conjunction is February 16


Mars
Jupiter
Ceres
Earth
Venus
Mercury

THE PLANETS IN THE SKY

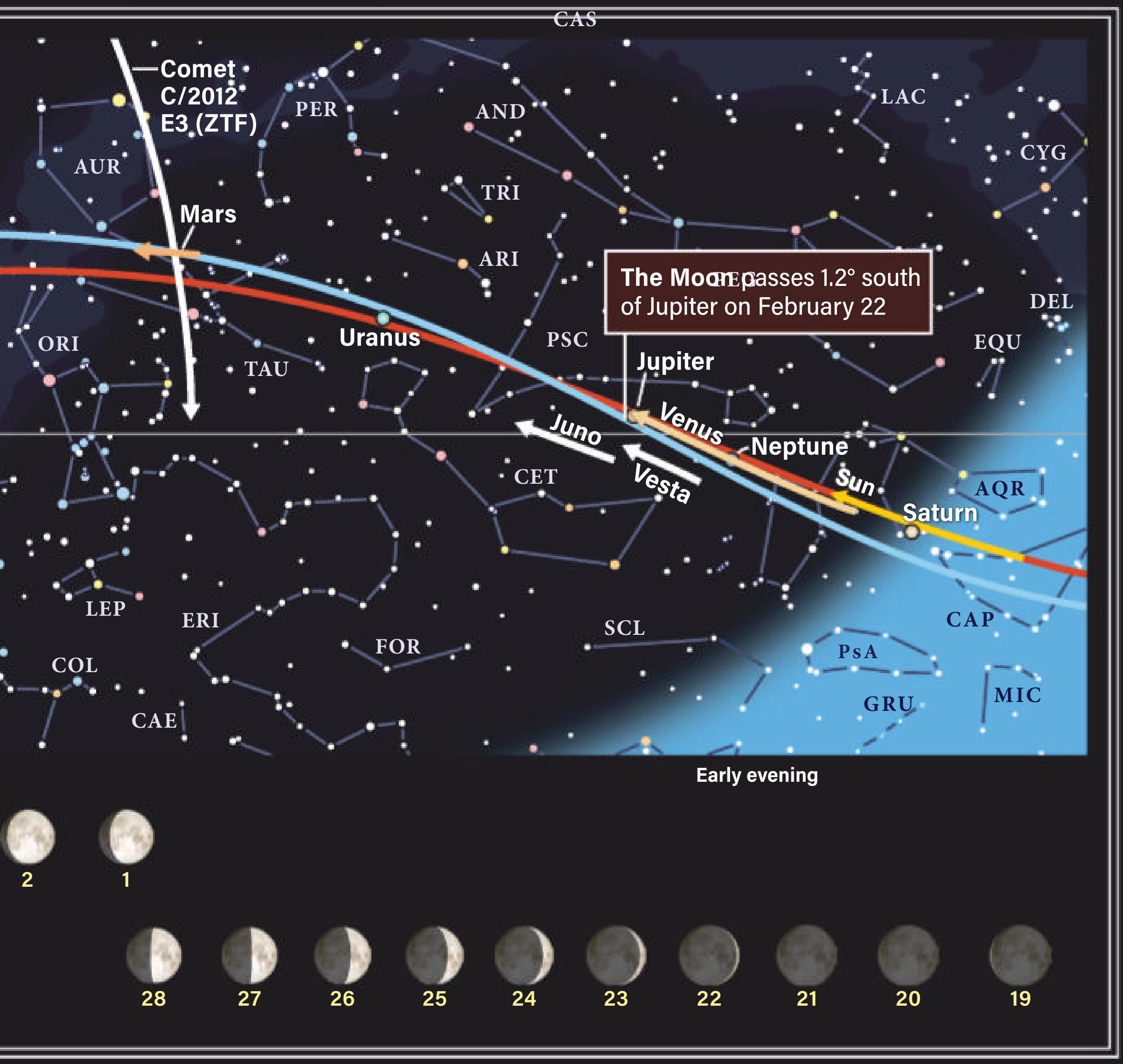
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Mercury
Venus
Mars
Ceres

PLANETS	MERCURY	VENUS
Date	Feb. 1	Feb. 15
Magnitude	–0.1	–3.9
Angular size	6.5"	11.6"
Illumination	66%	89%
Distance (AU) from Earth	1.030	1.440
Distance (AU) from Sun	0.437	0.724
Right ascension (2000.0)	19h11.8m	23h36.6m
Declination (2000.0)	–21°43'	–3°50'

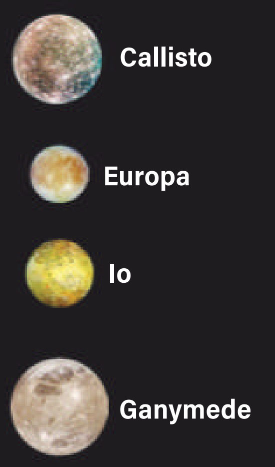
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

FEBRUARY 2023


CAS
Comet C/2012 E3 (ZTF)
PER
AND
LAC
CYG
AUR
TRI
Mars
ARI
DEL
ORI
Uranus
TAU
PSC
Jupiter
EQU
Juno
Venus
Neptune
Sun
CET
Vesta
AQR
Saturn
LEP
ERI
FOR
SCL
CAP
COL
PsA
GRU
MIC
CAE
2
1
28
27
26
25
24
23
22
21
20
19

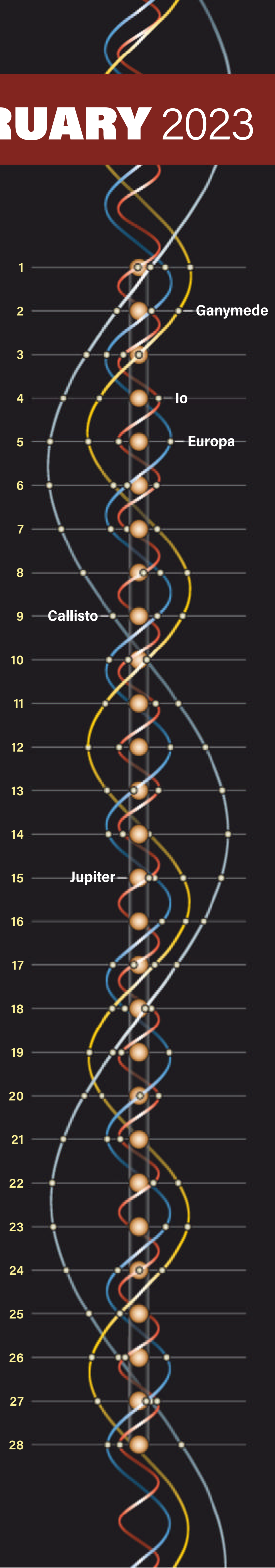
The Moon passes 1.2° south of Jupiter on February 22

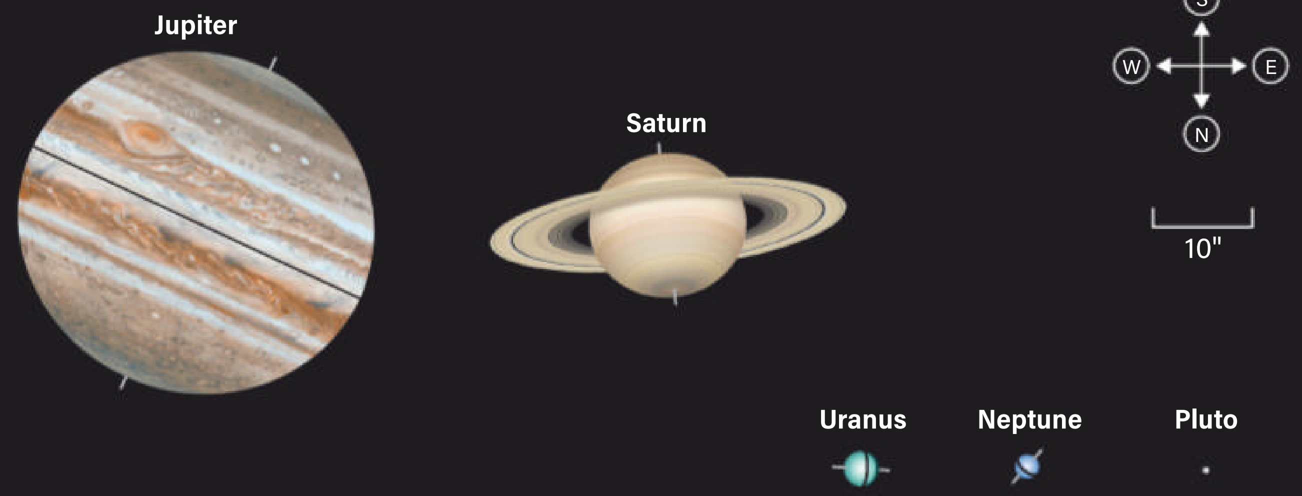
Early evening


Callisto
Europa
Io
Ganymede

JUPITER'S MOONS

Dots display positions of Galilean satellites at 9 P.M. EST on the date shown. South is at the top to match the view through a telescope.



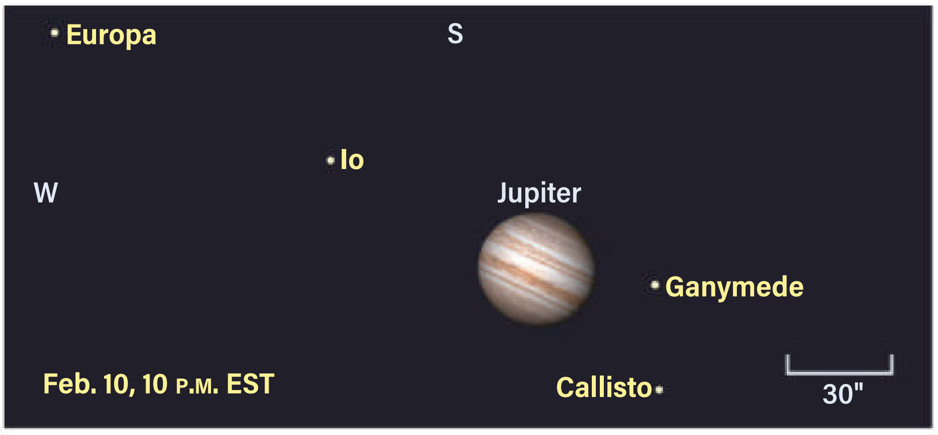

Jupiter
Saturn
S
W
E
N
10"
Uranus
Neptune
Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15
0.1	7.5	–2.1	0.7	5.8	7.8	15.2
9.3"	0.8"	35.0"	15.4"	3.6"	2.2"	0.1"
91%	98%	100%	100%	100%	100%	100%
1.007	1.745	5.630	10.811	19.825	30.779	35.584
1.614	2.558	4.951	9.824	19.663	29.912	34.708
4h48.0m	12h47.7m	0h33.1m	21h59.5m	2h50.0m	23h38.9m	20h05.7m
24°59'	11°53'	2°20'	–13°37'	15°58'	–3°34'	–22°40'

SKY THIS MONTH

— *Continued from page 29*

A different angle



On Feb. 10, Callisto appears to pass due north of Ganymede, thanks to the tilt of the Galilean moons' orbits with respect to Earth.

evening, it's adjacent to Jupiter, just three Moon-widths away.

On the last evening of February, Venus and Jupiter stand less than 1.3° apart, an attention-grabbing pair located low in the western evening sky. An hour after sunset, they stand nearly 20° high and remain visible until at least 8 P.M. local time, when they'll be blocked by any trees or local buildings. The pair will sit closer together on March 1 — we'll review that conjunction next month.

Jupiter is a fine target for telescopes of any size. Small scopes will easily reveal the four Galilean moons: Io, Europa, Ganymede, and Callisto shine from 5th to 6th magnitude. The disk of Jupiter, spanning 36" on Feb. 1 and dropping to 34" by Feb. 28, reveals a pair of dark belts straddling its equator. There's more to see with larger telescopes: subtle details of dramatic atmospheric phenomena carried by the gas giant's fast, sub-10-hour rotation period. Jupiter starts the month at magnitude –2.2 but quickly dims by 0.1 magnitude.

Usually, we see the Galilean moons strung out east or west of Jupiter. However, sometimes the moons appear in odd relative locations because of the tilt of their orbits with respect to our line of sight. Check out Callisto 30" due north of Ganymede on Feb. 10, around 10 P.M. EST. Callisto lies on the far side of its orbit just past superior conjunction, while Ganymede is on the near side and heading toward inferior conjunction.

A pair of transits tell us a lot about the moons' orbits. Observe Jupiter on both Feb. 13 and 17. On the 13th, look between about 7:22 P.M. and 8:00 P.M. EST to see Europa and its shadow. Check how far apart they appear. You can imagine where the Sun is located to cause the shadow to appear where it is. On the 17th, watch the planet from about 6:56 P.M. to 8:17 P.M. EST. Io and its shadow appear much closer together than Europa and its shadow did because Io's orbit is smaller. The transit is already underway for Midwest observers as twilight descends.

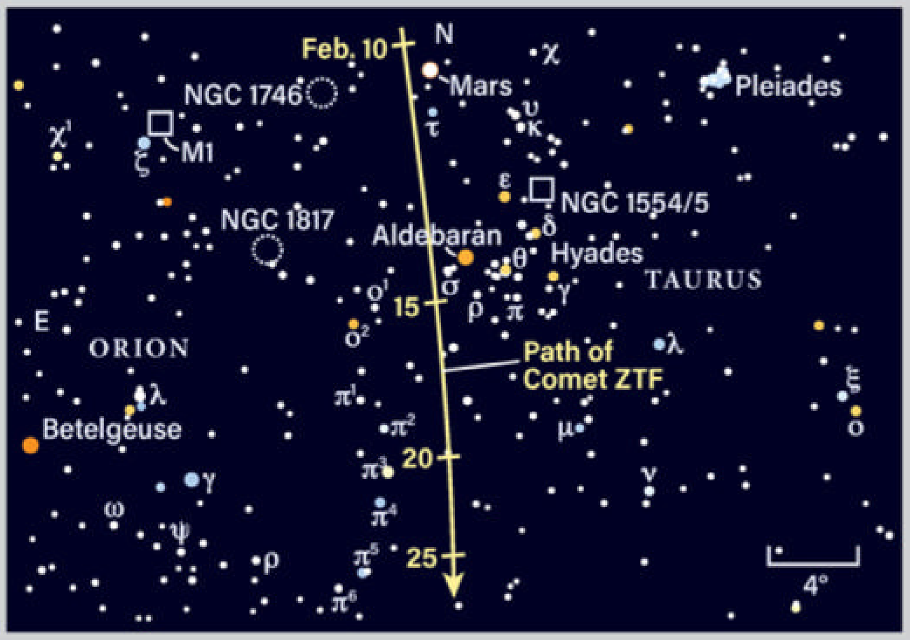
Uranus is an easy binocular target all month, located in a sparsely populated region of southern Aries. Three 5th-magnitude stars provide a useful signpost to this distant planet. Look for the triangle of stars formed by Sigma (σ), Pi (π), and Omicron (ο) Arietis. This triangle is 6° due north of

COMET SEARCH | All abuzz

WITH SO MUCH to experience this month, try observing Comet C/2022 E3 (ZTF) each clear night, no matter the Moon or light pollution. Rivaling the brightness of summer's M13 cluster at 5th magnitude, ZTF could be the best comet of the year. It's visible in the evening, has two tails, changes shape, and it really moves.

ZTF zips at 6° each night as February starts, when it is closest to Earth. It shifts obviously in just 10 minutes at the eyepiece. The comet then appears to decelerate to 3° per night by the 8th and slows to 1° each evening as March opens. It's all a trick of perspective.

Comet C/2022 E3 (ZTF)



Comet ZTF covers a large swath of sky this month; check our website for more details on its path in early February. The position of Mars is shown here on Feb. 10.

The comet sails through photogenic dark lane starfields by Friday the 10th and passes Mars, which lies at twice ZTF's current distance. For Perseverance, the 6th-magnitude comet appears 2° from magnitude –2 Earth in the martian sky.

Small scopes from the suburbs should show a narrow fan of dust getting broader as ZTF fades by a couple of magnitudes into New Moon. Switch to country skies if you can. Twelve-inch scopes ought to reveal some green in the coma, while imagers might get a blue gas tail lining the sharply defined south edge.

Farther north, magnitude 10 C/2020 V2 (ZTF) gets traded from Cassiopeia to her daughter, Andromeda. And observers south of the equator can watch 7th-magnitude C/2017 K2 (PanSTARRS) skirt a few degrees from the Small Magellanic Cloud.

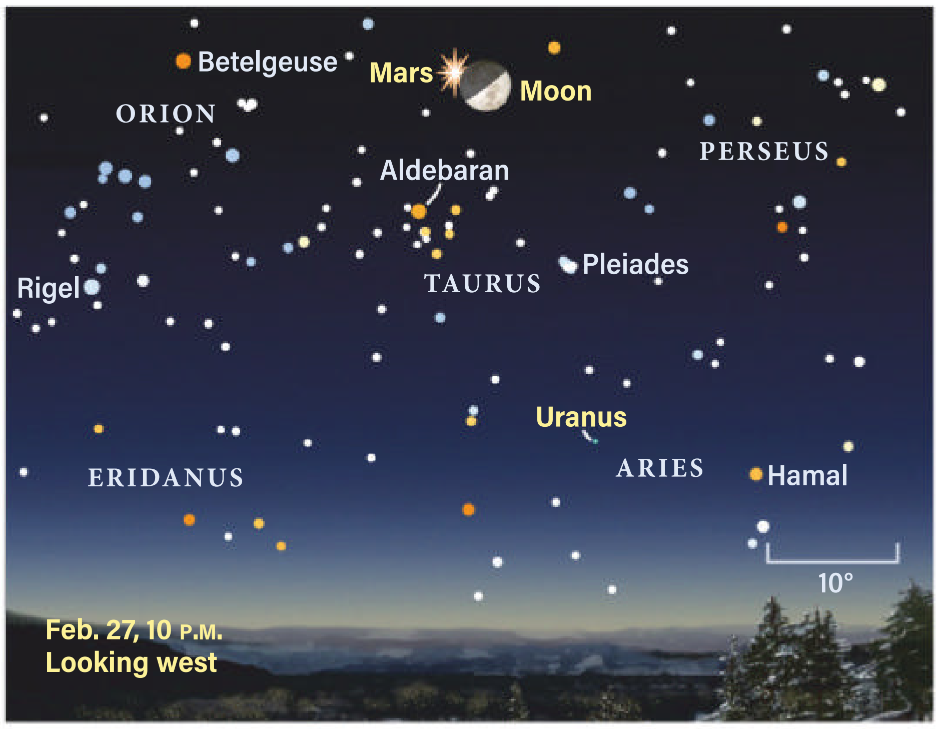
WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (west)
Mars (south)
Jupiter (west)
Saturn (west)
Uranus (southwest)
Neptune (west)

MIDNIGHT
Mars (west)
Uranus (west)

MORNING SKY
Mercury (east)

Red light



Near the end of the month, the First Quarter Moon joins Mars in Taurus. Uranus, in Aries, will require binoculars to spot.

Mu (μ) Ceti in the head of the Whale. Uranus is inside this triangle and moves northeast from night to night. By the last week of February, it lies roughly midway between Sigma and Pi. Uranus sets shortly after 11 P.M. local time at the end of month, so there's lots of dark time to catch it. A telescope reveals its 4"-wide pale bluish disk.

Mars shines brightly in Taurus the Bull, where it has spent most of the winter. It's well past its best but at magnitude –0.2, still outshines Aldebaran some 8° to its south on Feb. 1. Mars starts the month 10° due east of the Pleiades (M45) and slowly moves eastward each night.

Check Mars with binoculars on Feb. 10 and 11 for the possible appearance of a binocular comet (C/2022 E3 [ZTF]) nearby. If the comet gets bright enough, you may see very faint fuzzball 1.5° northeast of Mars on the 10th and less than 2° due south on the 11th.

Mars continues across northern Taurus and fades to magnitude 0.3. The month ends with Mars less than 5° southwest of Elnath (Beta [β] Tauri), the northern horn of the Bull. On Feb. 27, Mars stands about 1.5° east of a First Quarter Moon in the early evening. By midnight Eastern time, the Moon has wandered due north of Mars, with 1.1° separating them.

Mars is very small in telescopes and continues to shrink after its December peak. It spans 11" on Feb. 1 and slims to 8" by Feb. 28. Around 9 P.M. in the Central time zone, the following features lie on the Earth-facing hemisphere of Mars (determined for the mid-U.S.): Feb. 1: Tharsis and Valles Marineris; Feb. 8: Sinus Sabaeus and Mare Erythraeum; Feb. 15: Syrtis Major and Hellas; Feb. 22: Elysium and Mare Cimmerium; Feb. 28: Mare Sirenum, Amazonis, and Olympus Mons. Features will vary depending on the time you observe from your location.

Mercury appears low in the southeast before dawn. On Feb. 1, it stands nearly 4° high an hour before sunrise. Shining at magnitude –0.1, Mercury is a couple days past its greatest elongation west. It's located in eastern Sagittarius near the Teaspoon asterism. If you can spy the planet through a telescope, it shows a 67-percent-lit disk spanning 6".

A week later, Mercury has dropped to 1.5° high an hour before sunrise. It is now magnitude –0.1. By Feb. 14, it is brighter at –0.2 and visible 45 minutes before sunrise, quickly blending into the morning glow. Your final glimpse might be on the morning of Feb. 18, when a waning crescent Moon, just over a day from New, appears in the vicinity. Mercury sits 7° to the upper left of the Moon 30 minutes before sunrise.

Saturn is visible in the west for less than an hour after sunset in early February. It reaches conjunction with the Sun on Feb. 16 and will reappear in the morning sky next month.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

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LOCATING ASTEROIDS

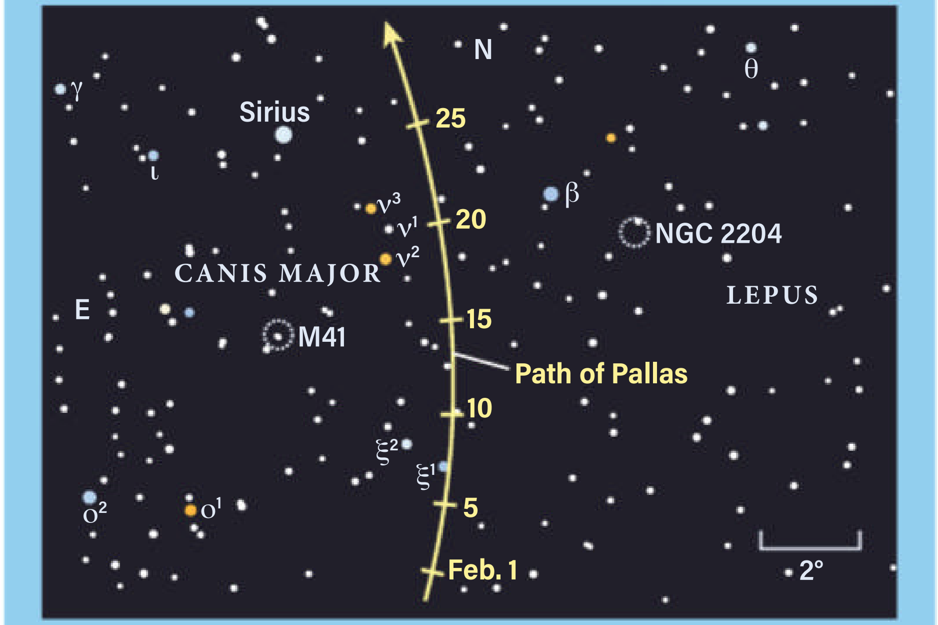
Pallas and the pooch

THE NO. 1 DOG, Canis Major, plays host to the No. 2 asteroid, Pallas, this month. Suitable for small scopes from the suburbs, Pallas glows at magnitude 7.7 just a short jump from the blazing blue-white Sirius. Thankfully, the main-belt asteroid lies so far south of the ecliptic that as the Moon passes way on the north side, Luna's light halo never interferes.

Despite the richness of the winter Milky Way, these stars are more distant than those visible in summer. Hence, they are fainter, allowing Pallas to stand out — so much so that nothing beats it until the 7th, when it slips through the field of 4th-magnitude Xi^1 (ξ^1) Canis Majoris. On the 22nd and 26th, two loose clutches of stars provide a reference to highlight Pallas' displacement in an hour.

Potato-shaped Pallas spans some 325 miles and was discovered by Heinrich Wilhelm Olbers in 1802, while he was painstakingly comparing the sky against star charts.

Bright lights ahead

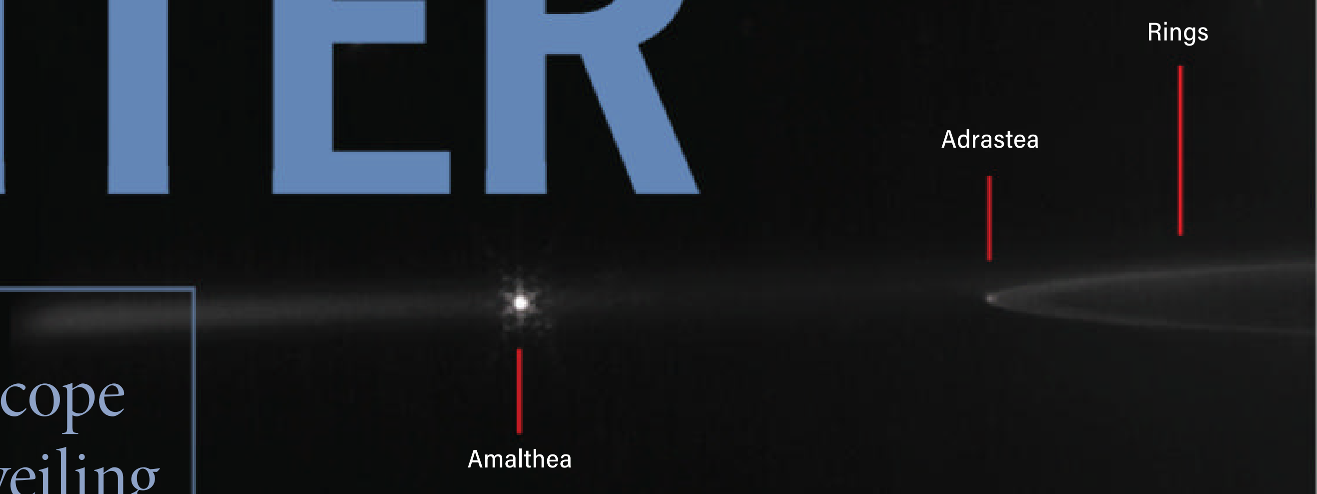


Pallas follows a curving path through Canis Major this month as it approaches the sky's brightest star.

JWST sets its sights on JUPITER

NASA's latest space telescope shows off its prowess, unveiling the ethereal beauty of the gas giant.

BY RICHARD TALCOTT



When the James Webb Space Telescope (JWST) blasted off from French Guiana Dec. 25, 2021, astronomers anticipated it would deliver breathtaking images of distant galaxies and star-forming regions, as well as analyze the chemical makeups of exoplanet atmospheres. And NASA's flagship space telescope has not disappointed.

JWST has already captured images of galaxies so far from Earth that cosmic expansion has shifted their light well into the infrared part of the spectrum, which the telescope is built to detect. And the observatory's Near-Infrared Spectrograph (NIRSpec) has even discovered carbon dioxide in the atmosphere of exoplanet WASP-39 b — the first definitive detection of this gas in a world beyond our solar system.

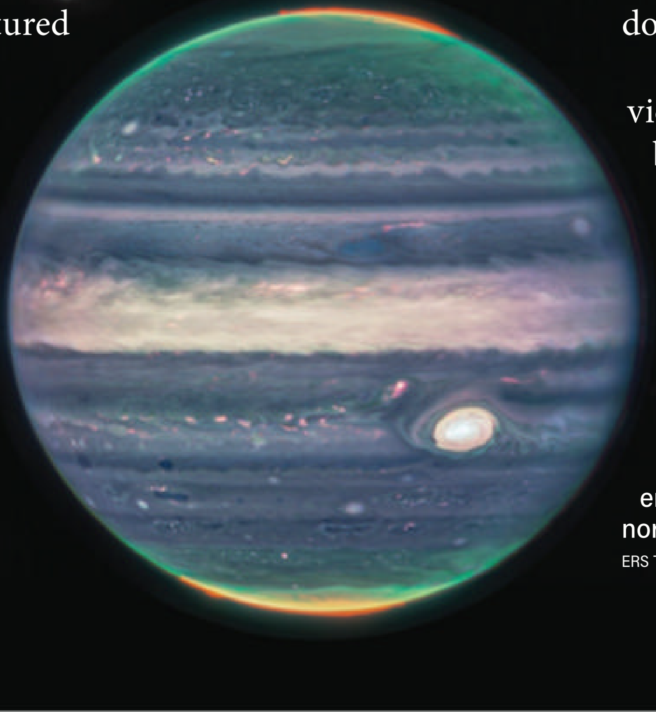
But JWST has set its sights closer to home, too. On July 27, astronomers targeted Jupiter with the telescope's powerful infrared eye. The resulting images reveal a planet both familiar and exotic. "We've never seen Jupiter like this. It's all quite incredible," said principal investigator Imke de Pater of the University of California, Berkeley, in a statement. "We hadn't really expected it to be this good."

JWST's Near-Infrared Camera (NIRCam) captured two images of our solar system's largest planet. In the striking close-up (right), taken through three different filters, Jupiter displays numerous cloud bands, as well as storms and auroral emissions. The Equatorial Zone spans the planet's girth and looks bright white because its high-altitude hazes reflect lots of sunlight. For the same reason, the massive Great Red Spot in Jupiter's southern hemisphere shows up as a bright oval. Smaller storms across the planet appear whitish or reddish white.

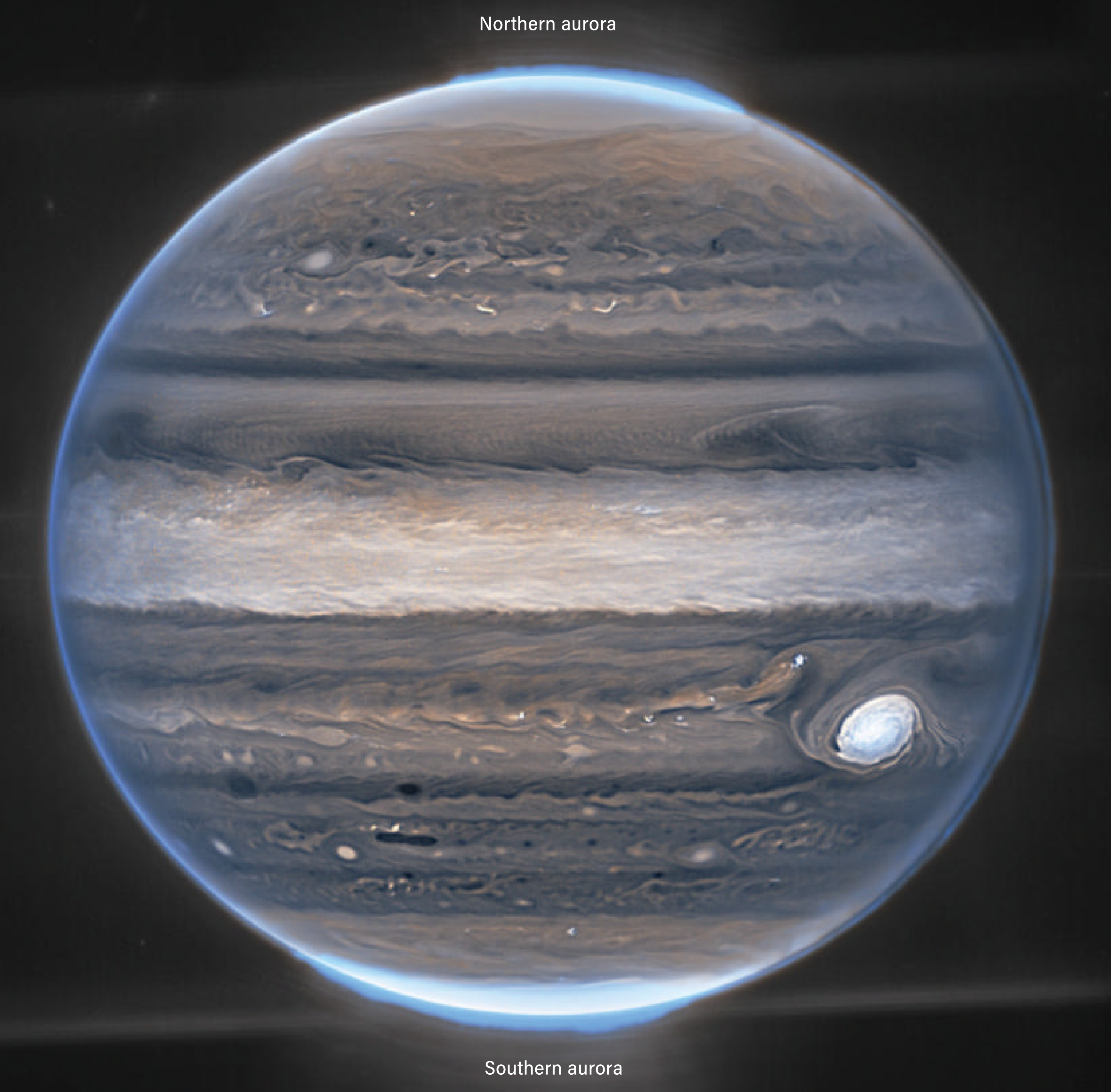
The cyan hues, meanwhile, reveal clouds buried deeper in the jovian atmosphere, showing light reflected from the planet's main cloud level at a pressure of about 1 bar (roughly the atmospheric pressure at Earth's surface). The image also showcases the transition between the banded structures seen at equatorial and mid-latitude regions — a favorite among earthbound observers — plus more complex vortices at higher latitudes.

Jupiter's massive auroral ovals appear as reddish glows near the giant's north and south poles. These emissions come from ionized hydrogen atoms that extend up to 625 miles (1,000 kilometers) above the cloud tops. The greenish areas around the poles come from hazes in the gas giant's atmosphere located about 60 to 120 miles (100 to 200 km) high. If you look carefully, you can trace this haze layer along the limb down to equatorial latitudes.

The spectacular wide-field view of Jupiter (top) combines images through two



← Jupiter's Equatorial Zone and Great Red Spot stand out in this infrared image from the James Webb Space Telescope because their high-altitude hazes reflect sunlight well. Also note the bright auroral emissions near the giant planet's north and south poles. NASA/ESA/CSA/JUPITER ERS TEAM/JUDY SCHMIDT



Jupiter's magnificent cloud tops are but one highlight of this wide-field image, which includes the planet's dusty ring system as well as the moons Amalthea (left) and Adrastea (left edge of rings). NASA/ESA/CSA/JUPITER ERS TEAM/ RICARDO HUESO ALONSO/JUDY SCHMIDT

infrared filters. The jovian clouds and aurorae still stand out, but many more details appear in this composite photo. The power of JWST is exemplified by its ability to capture Jupiter's faint and dusty rings in the same image as the planet itself, which shines 1 million times brighter than the rings. Also present are two faint inner moons: Amalthea (155 miles [250 km] in diameter) and Adrastea (12 miles [20 km] across). Adrastea is a dim dot at the edge of the rings to the left of the planet while Amalthea lies about twice as far from Jupiter's limb.

A background of scattered light also permeates the image. The most obvious sources are diffraction spikes from Jupiter's aurorae and the bright moon Io, which lies just beyond the left-hand edge of the image. The latter spike intersects the two visible moons. Diffraction spikes arise in reflecting telescopes like JWST when light interacts with the struts that support its secondary mirror. A more intriguing form of background light appears in the form of fuzzy dots, visible off of Jupiter's left limb and scattered throughout this text: Scientists think these objects are actually distant galaxies that photobombed the image.

The colors in these images don't match what the human eye would see when observing Jupiter. After all, our vision does not pick up infrared radiation. But the image processors for these stunning shots — citizen scientist Judy Schmidt and Ricardo Hueso of the University of the Basque Country in Spain — mapped longer infrared wavelengths to the red end of the visible spectrum and shorter wavelengths toward the blue, mimicking how the human eye perceives visible light. In the close-up image of Jupiter's disk, the team mapped wavelengths of 3.6 micrometers to red-orange, 2.12 micrometers to yellow-green, and 1.5 micrometers to cyan. In the wide-field view showing the world's surroundings, they mapped wavelengths of 3.35 micrometers to cyan and 2.12 micrometers to orange.

But while these images are certainly eye-catching, they're just one aspect of JWST's observing prowess; the telescope's spectroscopic capabilities are also being brought to bear on Jupiter. On July 27, astronomers took spectra of the Great Red Spot at near-infrared wavelengths and carried out similar observations in the mid-infrared Aug. 14 and 15. Jupiter's aurorae also came under closer spectroscopic scrutiny late last year.

JWST scientists have high hopes for what the next-gen space telescope can teach them about the jovian system. Researchers plan to analyze the world's cloud layers, composition, temperature, winds, and auroral activity. Astronomers also wish to better understand the structure of Jupiter's ring system, providing insight into where it originates and how it will evolve. And planetary scientists expect to create maps of the surface and atmosphere of both the volcanically active moon Io and the icy moon Ganymede. These satellite observations will also search for plumes of volcanic gases (Io) and water vapor (Ganymede).

It's an ambitious undertaking, but if JWST's initial observations prove anything, it's that the telescope should be more than up to the task.

Contributing editor **Richard Talcott** *has covered Hubble results for more than 30 years, and looks forward to a similarly long partnership with JWST.*

THE TUCSON TR

America's astronomical nexus

IANGLE

This trio of observatories is the greatest collection of scopes and spectrographs in the continental U.S.

BY RANDALL HYMAN

Amid the burning Arizona sands, three peaks form a triangle of superlatives surrounding Tucson. Atop Mount Graham sits the world's largest optical telescope. Mount Hopkins is home to North America's second-largest single-mirror telescope. And Kitt Peak contains the continent's largest single collection of mountaintop astronomical instruments.

The dry air and mountainous terrain around Tucson make this power trio the core of optical astronomy in the continental U.S. The observatories are historic — the oldest, Kitt Peak National Observatory (KPNO), was founded in 1958 and its flagship Mayall telescope turns 50 this year. Yet their constant innovations have made them magnets for astronomers worldwide. Facilities on all three mountaintops are doing cutting-edge research on some of astronomy's hottest topics, from dark energy to exoplanets, with inventive instrumentation.

Telescopes reborn

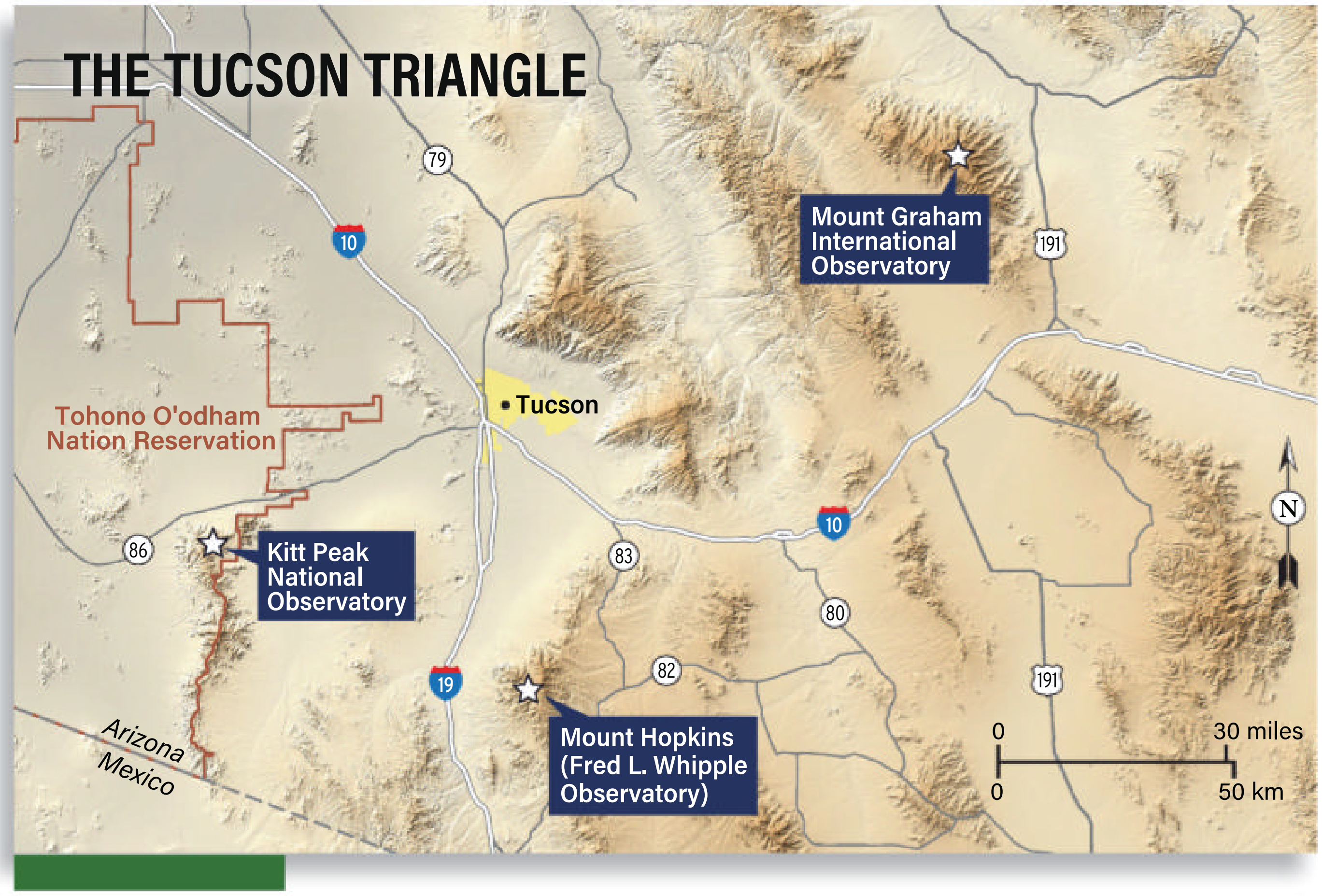
Last summer, I set out to explore the Triangle, determined to find out how these observatories were adapting to today's challenges, including weathering the COVID-19 pandemic and the increasing threat of devastating forest fires.

In June, the entire KPNO complex narrowly escaped annihilation in the nearly 29,500-acre Contreras Fire. But when the smoke cleared, KPNO's 18-story Mayall telescope dome was still standing, visible from Tucson 40 miles (64 kilometers) to the northeast and towering above almost two dozen smaller domes.

The Mayall and the 18-story-tall building that houses it date from a time when tall domes were considered crucial for still air and optimal observing. That concept was eventually abandoned for simpler, more compact designs, but the long elevator ride to the top-floor control room still inspires visions of astronomers peering skyward from precarious ladders.

The telescope has retained its original 15-ton,

The 4-meter Mayall telescope (center) dominates the skyline of Kitt Peak National Observatory. The lights of Tucson are visible in the background. KPNO/NOIRLAB/NSF/AURA


THE TUCSON TRIANGLE
79
10
Mount Graham International Observatory
191
Tucson
Tohono O'odham Nation Reservation
10
N
86
Kitt Peak National Observatory
83
80
82
19
191
Mount Hopkins (Fred L. Whipple Observatory)
Arizona
Mexico
0
30 miles
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50 km

ABOVE: Kitt Peak, Mount Graham, and Mount Hopkins form a scalene triangle around Tucson, making it a North American mecca for astronomy research.

ASTRONOMY: ROEN KELLY

CENTER RIGHT: In 2002, an adaptive optics system was installed on the MMT. A laser serves as an artificial guide star that indicates how turbulence in the atmosphere is distorting the telescope's image; a deformable secondary mirror subtly and rapidly shifts shape to correct the image.

MMT OBSERVATORY

BOTTOM RIGHT: The Mayall telescope's enormous equatorial mount is a mechanical marvel. However, most observatories today use simpler and cheaper alt-azimuth mounts, relying on improved tracking technology.

MARILYN CHUNG/LAWRENCE BERKELEY NATIONAL LAB/KPNO/NOIRLAB/NSF/AURA

4-meter solid glass primary mirror and equatorial mount. “It’s a behemoth,” says Kitt Peak’s associate director, Michelle Edwards, and, in some ways, a relic. “But the bang for the buck comes with the instrumentation that you put on a telescope. You can take a telescope that is 40 years old and put in leading-edge instrumentation, and you basically are at the forefront of science.”

That’s what KPNO and its owner, the National Science Foundation (NSF), did to the Mayall in 2018, when engineers replaced its secondary mirror with a state-of-the-art spectrograph called the Dark Energy Spectroscopic Instrument (DESI). The instrument was built with funding from the Department of Energy for a singular, five-year mission: to determine the role of dark energy in the universe’s ongoing expansion. Since 2021, DESI has been collecting data from over 30 million distant galaxies to create a three-dimensional map of the universe, reconstructing how it has evolved since the Big Bang.

DESI is one of the most powerful instruments of its kind in the world. With a field of view 38 times larger than the Full Moon, it can obtain spectra of extremely faint galaxies up to 12 billion years old using 5,000 robotically positioned optical fibers. Inside DESI, six lenses focus light from the Mayall’s primary mirror onto optical fibers split into 10 bundles of 500 strands each, which lead to a sealed room one floor below. The fibers produce spectra of thousands of galaxies with each exposure, divided into red, blue, and near-infrared wavelengths.

The spectra reveal vital details about each galaxy: age, distance, and velocity. All of these measurements are based on cosmological redshift, the stretching of light toward longer (redder) wavelengths as the universe expands. The faster the universe is expanding and the farther an object’s distance, the redder it appears.

Seeing the unseeable

While DESI measures cosmological redshift, Kitt Peak’s other new instrument, attached to the 3.5-meter WIYN telescope and called NEID (pronounced noo-id), measures the more familiar Doppler shift: the way wavelengths are stretched or compressed by the motion of an object moving away or toward us, like the sound waves of an ambulance siren. Astronomers can then use the information to determine the radial velocity, or “wobble,” of a star, indicating the possible presence of an unseen exoplanet.

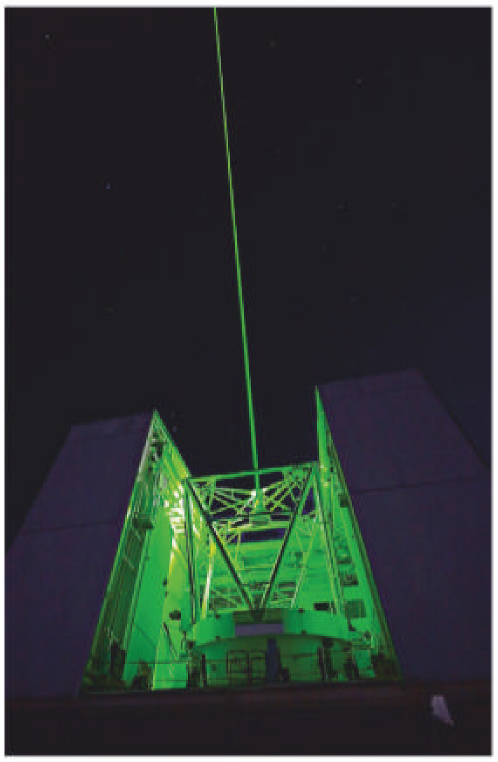
NEID is named after the word “to see” in the language of the Tohono O’odham, the Native

American people on whose land Kitt Peak lies. (It also stands for NN-EXPLORE Exoplanet Investigation with Doppler Spectroscopy.) NEID is a much smaller spectroscope than DESI, with a single optical fiber that detects how much a star appears to wobble back and forth on the sky due to the gravitational tug of its exoplanets.

All of NEID's key hardware is isolated inside a vacuum-sealed room. This helps make NEID three times more sensitive than the previous generation of radial velocity detectors. Despite the enormous distances of the stars it measures, NEID can detect a star wobbling as slowly as a baby crawls, about a foot (30 centimeters) per second. The wobble's speed gives astronomers a precise read on the masses of exoplanets in the system, down to planets nearly as small as Earth.

Although WIYN's alt-azimuth mount makes it more compact than the Mayall, its key innovation was its lightweight primary mirror: WIYN was one of the first telescopes of its size to experiment with honeycombed, spun-glass mirrors pioneered by the University of Arizona's Richard F. Caris Mirror Lab in Tucson. "The telescope here was built as a testbed for, 'How do we eventually build bigger telescopes?'" says Emily Hunting, WIYN's optical engineer. Though only about 23 percent smaller than the Mayall's primary mirror in area, WIYN's mirror is nearly seven times lighter.

WIYN saw first light in 1994, and Caris mirrors are now the gold standard for top-tier optical telescopes worldwide. Caris also makes the largest mirrors in the world at 8.4 meters wide. Seven of these are being installed at the Giant Magellan Telescope in Chile — and two already power the Large Binocular Telescope (LBT) on Mount Graham.



Inside a colossus

The LBT is the second corner of the Tucson Triangle, some 100 miles (160 km) northeast of Kitt Peak and 70 miles (113 km) northeast of Tucson.

If the Mayall is a behemoth, as Edwards calls it, LBT is a colossus. "It's about as tall as the Arc de Triomphe," says former LBT director Christian Veillet, who relinquished the post last year after 10 years managing LBT, but remains on staff.

The lowest three stories of the building are painted green and support a hulking white edifice several times as high that rotates each night to track stars. Inside the cavernous telescope dome, a pair of massive, multistory steel gears ride on a thin layer of oil, tilting the twin mirrors skyward with silent majesty as giant doors gradually pull open to reveal a bejeweled black sky.

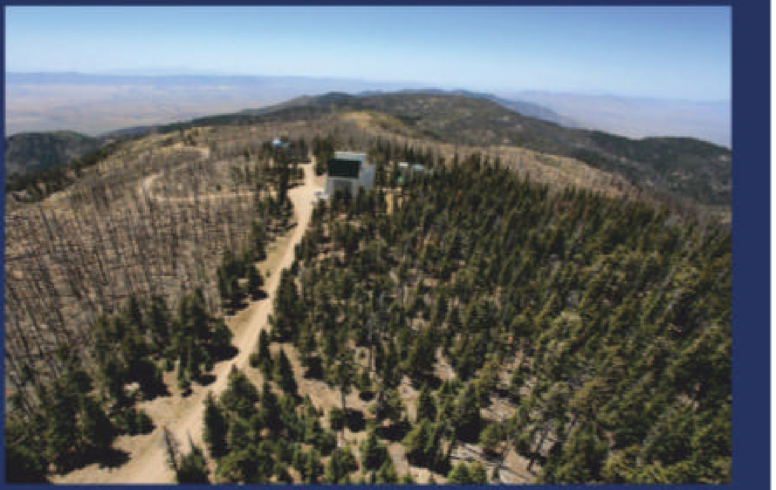
All aspects of the LBT are staggering in size and scope. Although the ingenious design is efficient in driving twin mirrors on a single mount, having two primaries means that there are two of almost everything else,

SKY ISLANDS AFLAME

KITT PEAK, MOUNT GRAHAM, AND MOUNT HOPKINS are examples of what ecologists call "sky islands," renowned for their verdant alpine ecosystems. They are also increasingly prone to devastating fires amid a prolonged, historic drought linked to climate change.

Mount Graham has survived three blazes since 1996, and in May 2022, Mount Hopkins escaped a smaller fire that was quickly doused.

Most recently, on June 11, 2022, lightning struck a remote ridge near Kitt Peak National Observatory (KPNO), igniting the Contreras Fire. As a wall of flames marched inexorably toward the observatory, firefighting crews fought from land and sky across the rugged terrain. By June 17, fires had obscured two radio telescopes and incinerated several dorms and outbuildings. When the smoke cleared on June 19, KPNO officials, fearing the worst, were allowed access — and discovered that all science equipment had miraculously survived the inferno. *—R.H.*



The vestiges of forest fires that engulfed Mount Graham International Observatory in 2004 and 2017 unfold below the Large Binocular Telescope. The devastation wraps around the nearby 10-meter Sub-Millimeter Telescope (right) — part of the global radio array that captured the first image of a black hole in 2017 — and the adjacent Vatican Advanced Technology Telescope (VATT; left). Neither were damaged in the blazes, but when staff regained access to VATT just hours after the last flames were extinguished yards away from the dome, the building's windows were still too hot to touch. RANDALL HYMAN from enormous science instruments — some larger than SUVs — to the complicated mechanisms that switch between them.

In the middle of the night, the fourth-floor corridor becomes a carnival funhouse where everything changes position. It's the transition floor between the observatory's base and the rotating dome, so anyone going up or down has to transfer between elevators — and the two shafts change their positions whenever the dome rotates. Astronomers rely on colored lines painted along the dimly lit circular hallway to navigate to the correct elevator.

"Blue leads up to heaven, red takes you down to, well, the control room," says Veillet with a wry smile.

Twins' reunion

In May 2022, the key instrument linking the LBT's two mirrors was pressed back into service after a long, COVID-imposed respite. It is called LBTI, with *I* signifying interferometer, an instrument that melds the light from the two mirrors into one.

For the previous two years, the LBT's mirrors were used individually for separate missions, but their combined power is the telescope's raison d'être — it's the largest single-mount binocular telescope in the world. When working together in phase, the signals from each mirror produce an interference pattern of fringes. By analyzing these fringes, scientists can construct a higher-resolution virtual signal. The result is an image as sharp as if the instrument had a single mirror the size of both mirrors combined, effectively 23 meters in diameter, and with a field of view 10 times wider than that of the Hubble Space Telescope.

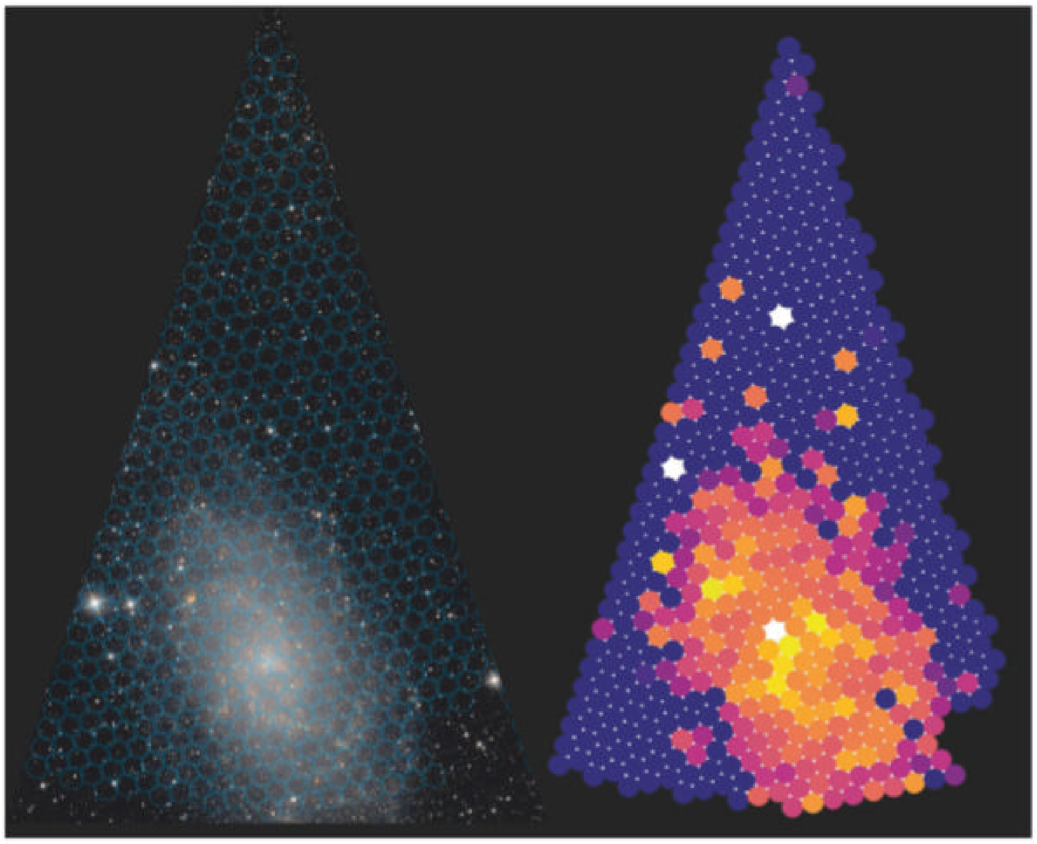
But on the night that I visited, they weren't quite there yet. Operating the pair in tandem is "super exciting and also super challenging," says Steve Ertel, lead scientist for LBTI. "We've seen some fringes … but we've not yet been successful locking the interferometry phase between the two sides to get back to what we need for science."

When not flexing its interferometry abilities, LBT serves as a simple infrared imager using a single mirror. "The project we're doing right now is also exciting," says Ertel, "looking for giant planets in the habitable zone around very nearby stars. We will be able to go down to super-Earth-mass planets when LBTI's back, but I find giant planets more exciting. If you find a giant planet in the habitable zone, you have a good chance of rocky moons, so the probability of life there is a lot higher."

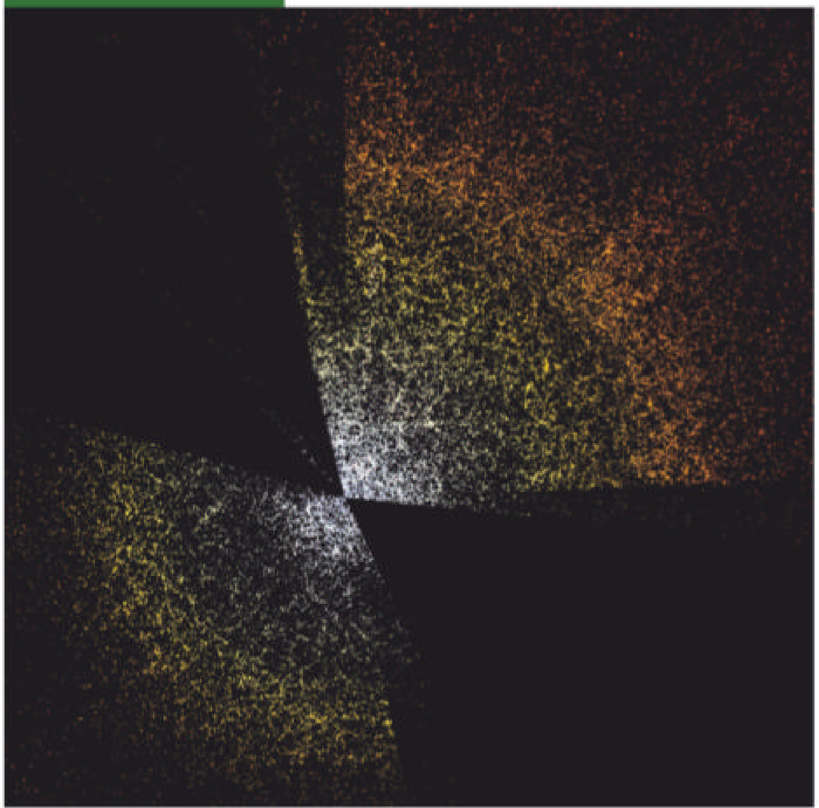
Realm of the mountain king

From afar, the dome of the MMT Observatory atop Mount Hopkins strikes a regal profile. It lies 90 miles (145 km) southwest of Mount Graham and 45 miles (75 km) southeast of Kitt Peak, sitting alone on the peak like a mountain king on a craggy throne.

The exposed position has a benefit, explains Grant Williams, the director of the MMT, which is part of the Fred L. Whipple Observatory on Mount Hopkins. "When there are prevailing winds, it's a laminar [smooth] flow over the telescope rather than being turbulent," he says — which means better seeing and image clarity.

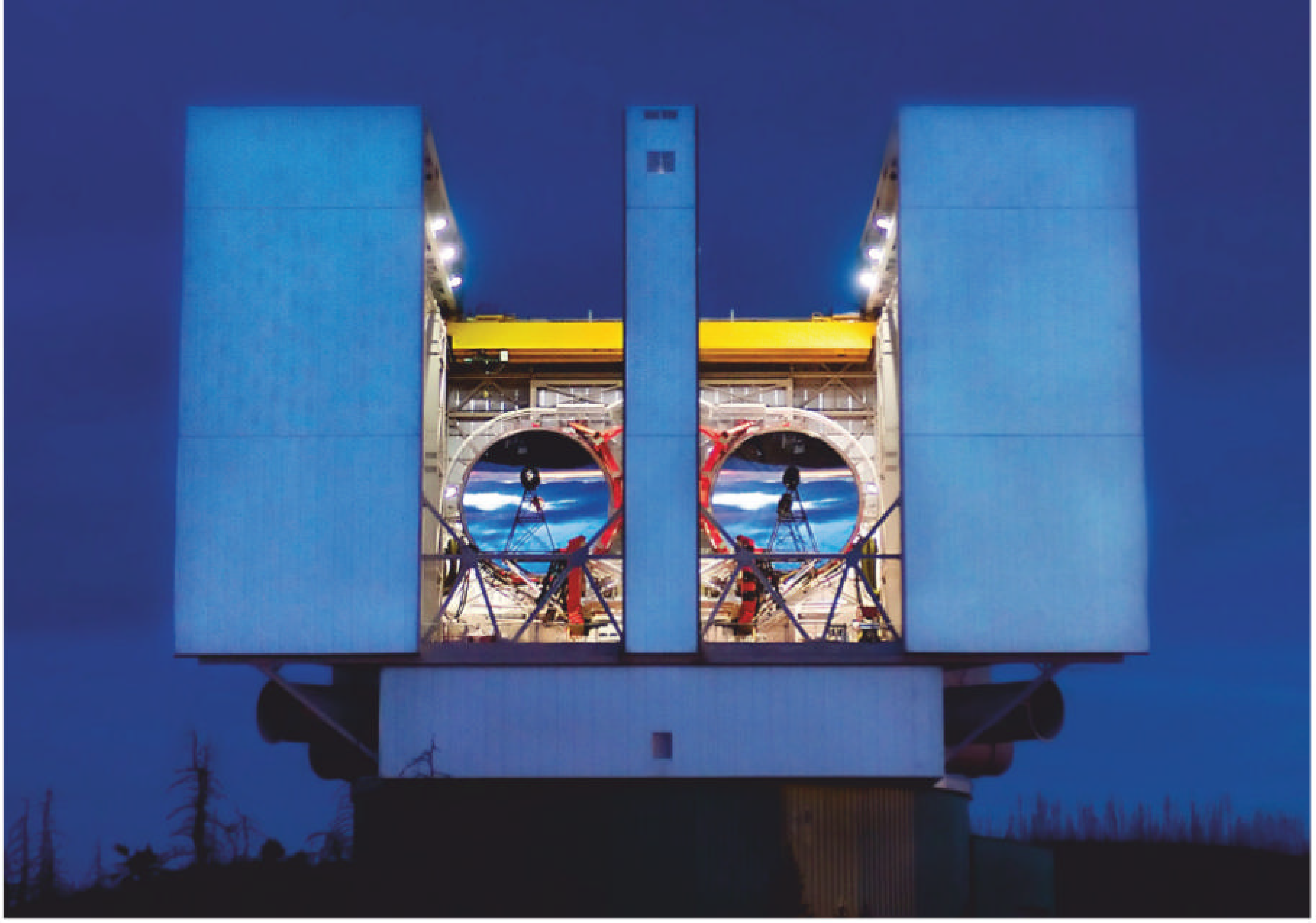


RIGHT: M33 sits in DESI's field of view at left, which is marked with blue circles that indicate the region of sky that each of the 500 fibers can study. They can be precisely positioned on any target within each blue circle. The color map at right shows the strength of hydrogen emission in the field of view, where brighter colors correspond to stronger emission. DESI COLLABORATION/NOIRLAB/NSF/AURA

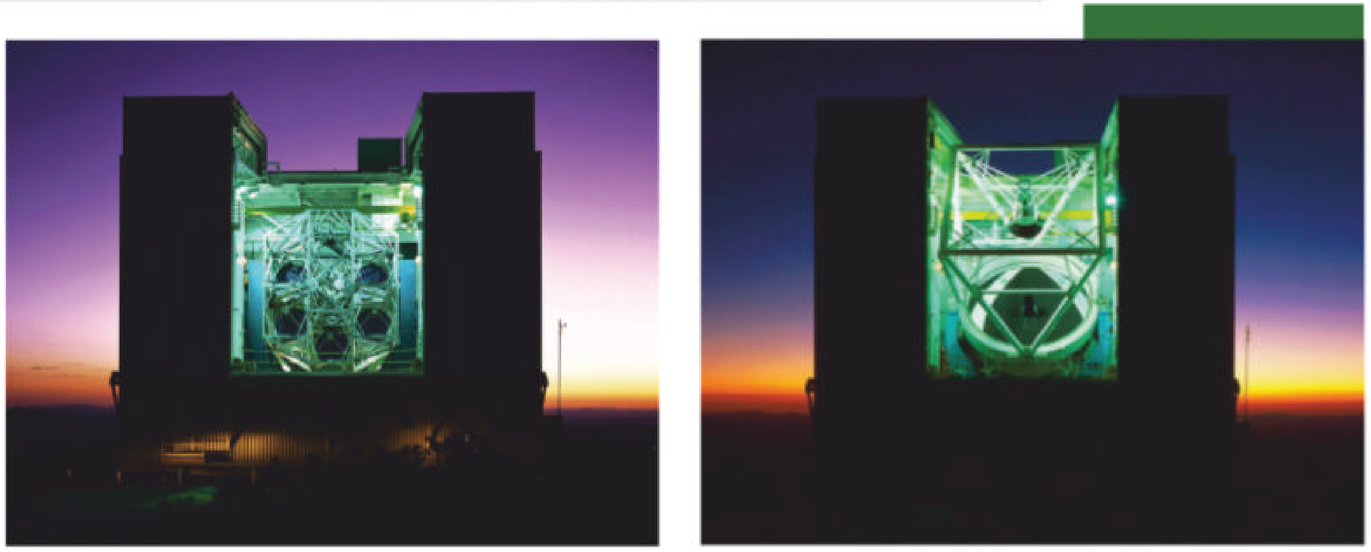


BELOW: DESI's first few months of operation produced a 3D map of galaxies as far as 10 billion light-years. This is a single slice of the map representing 400,000 galaxies, with Earth at the center. D. SCHLEGEL/BERKELEY LAB USING DATA FROM DESI. ACKNOWLEDGMENT: M. ZAMANI (NSF'S NOIRLAB)

BOTTOM RIGHT: Optical engineer Emily Hunting poses beside the 3.5-meter primary mirror of the WIYN telescope that she helps maintain at Kitt Peak National Observatory. RANDALL HYMAN



LEFT: The Large Binocular Telescope on Mount Graham is the largest pair of telescopes on a single mount in the world. LBTO



BELOW: In the MMT's original incarnation (left), it was called the Multiple Mirror Telescope. In 2000, it was changed to a single-mirror configuration (right). MMT OBSERVATORY

If the Mayall is a behemoth, the Large Binocular Telescope is a colossus.

When the MMT saw first light in 1979, it was the third-largest optical telescope in the world. Then, the telescope comprised six separate mirrors left over from a canceled military project; its acronym stood for Multiple Mirror Telescope. However, in 2000, the MMT was converted to a single mirror. And in 2002, it was enhanced with the world's first adaptive optics system to use a deformable secondary mirror for correcting atmospheric turbulence. Previous systems made corrections further down the line in the optical train, but deforming the secondary mirror itself sends sharp images directly to science instruments.

On the night I visited, prevailing southwesterlies topped 35 mph (56 km/h). These gusts weren't a problem, but computer gremlins were a showstopper. An instrument switchover earlier in the day from an infrared imager to a spectroscope was creating software issues that ultimately scrubbed operations for the night.

On a ridge 1,000 feet (300 m) below, though, three smaller domes housing 1.2-, 1.3-, and 1.5-meter telescopes were in business, searching for exoplanets. Several smaller scopes operating from a low hut and a nearby array of individually housed commercial scopes also took part in the hunt.

"The Ridge is almost all exoplanets," says Pascal Fortin, director of Whipple Observatory. The 1.2-meter telescope performed the initial sky survey for Kepler, NASA's wildly successful planet-hunting mission. "We found the best places for Kepler to look, and it discovered over 3,000 in that small field," he says.

Breaking light's speed limit

The Ridge was also the site for Whipple's very first astronomical instrument, a 10-meter gamma-ray detector installed in 1968. In 2007, its successor was put in. The Very Energetic Radiation Imaging Telescope Array System (VERITAS) is located at the base of Mount Hopkins and consists of four detectors. Each features a segmented 12-meter mirror with a longer focal length and less optical aberration.

Gamma rays are the most

SACRED PEAKS

ALL THREE PEAKS OF THE TUCSON TRIANGLE — Kitt Peak, Mount Graham, and Mount Hopkins — are sacred to the Native American tribes that call the respective regions home. Kitt Peak sits within the Tohono O'odham Nation Reservation; the Tohono O'odham Nation agreed to lease the site to the observatory in 1958, though not without trepidation. In the early 1980s, the construction of Mount Graham International Observatory faced opposition from Apaches — amplified by the Large Binocular Telescope's original name, the Columbus Telescope. And in 2000, plans for the proposed site of VERITAS on Mount Hopkins were blocked by the U.S. Forest Service due to the proximity of a Native American sweat lodge where sacred rituals were performed. Astronomers then planned to mount VERITAS at Kitt Peak; this was opposed by the Tohono O'odham Nation and eventually abandoned. In 2007, VERITAS was installed at its present site at Mount Hopkins near the Whipple Observatory visitor center. *—Mark Zastrow*

ABOVE: Astronomer Qi Feng removes the cover from an array of photomultiplier tubes that are part of the gamma-ray detectors of the Very Energetic Radiation Imaging Telescope Array System (VERITAS) at Mount Hopkins. RANDALL HYMAN

RIGHT: Stars leave trails in this long-exposure image of the 3.5-meter WIYN telescope at Kitt Peak. KPNO/NOIRLAB/NSF/AURA/P. MARENFELD

energetic form of radiation on the electromagnetic spectrum. VERITAS focuses on the most extreme gamma rays of all, so powerful they can't be reproduced in a lab. When these rays hit our atmosphere, they create thousands of electrons and positrons that exceed the speed of light in air. (The speed of light when unimpeded in a vacuum is still the ultimate speed limit of the universe.)

Similar to a sonic boom, breaking the local light-speed limit generates a brief burst of blue light called Cherenkov radiation. A cascading chain of electron-positron pairs collides with more air molecules, producing a glowing shower the size of two football fields, some 6 miles (10 km) above the ground. It lasts only nanoseconds, but VERITAS reacts just as quickly, capturing data about the extreme environments where such gamma rays are born: supernovae, neutron stars, and black holes.

By placing the four VERITAS telescopes some 300 feet (90 m) apart, scientists can pinpoint where the gamma rays originated as well as minimize superfluous noise from other particles. Each VERITAS telescope uses 350 mirrors to focus light on a single camera containing a dazzling array of 499 photomultiplier tubes, one per pixel.

VERITAS is at the base of the mountain because "there is a sweet spot of how far away you want to be from those showers," Qi Feng, an astrophysicist and postdoc working at Whipple, explains. "If we are at 4 kilometers [2.5 miles] on the mountain, the showers will be right above us. That's going to be huge, and it's going to be very hard to design the optics to catch those. So, we can't be too high."

Lure of the triangle

This year, all three observatories are celebrating milestone anniversaries and the restart of public programs after a three-year respite during the pandemic.

Mount Graham is marking its 30th anniversary as an international observatory, while LBT celebrates its 15th since first light. Whipple turns 55, and KPNO will be celebrating its 65th birthday as America's first national observatory. NSF has also begun converting Kitt Peak's retired solar observatory into a $4 million interactive science museum, scheduled to open this year.

It is an auspicious time for the trio as the public is welcomed back and renovations continue. From dark energy to black holes to the search for life in habitable exoplanet zones, the Tucson Triangle beckons.

Randall Hyman *is a journalist and photographer whose work has been featured in numerous publications, including* Smithsonian, Science, *and* The Atlantic.

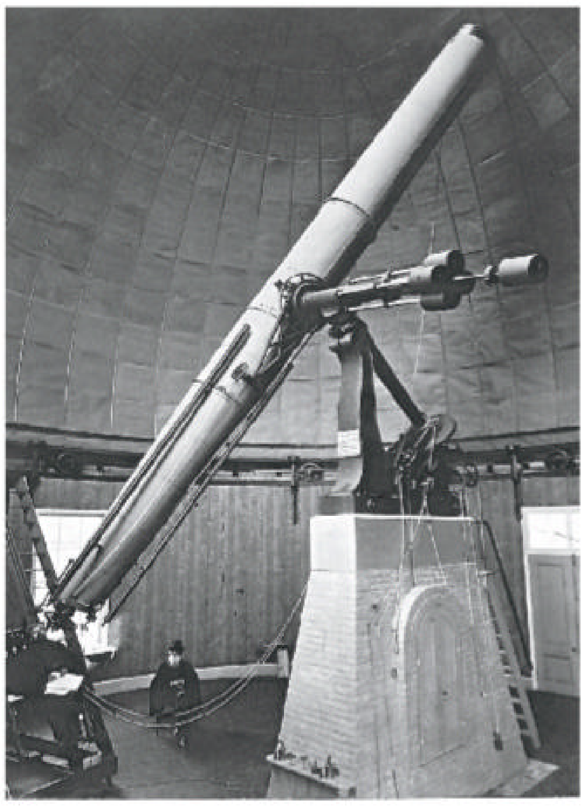
The Navy’s great refractor turns 150

From martian moons to double stars, this historic telescope made its mark on the field.

BY BRIAN D. MASON

IT WAS 1868, and the United States Naval Observatory (USNO) had a problem on its hands. Despite its importance as the nation’s official timekeeper and prestige as an astronomical research institute, its equipment was lagging in one crucial aspect: size. The largest telescope at the USNO was a 9.6-inch refractor — inadequate for tackling many of the most important observations of the era, like the moons of the outer planets.

That year, in a report to the Navy’s bureau chief of navigation, the USNO’s superintendent Benjamin Sands lamented: “The comparatively small size of the instrument prevents it from entering into competition with many telescopes of other observatories in the observation of faint objects.” Even more embarrassing, the 9.6-inch scope was not “at all comparable with many owned by colleges, observatories and private individuals throughout the country.” Sands added: “This will seem the more remarkable since the most successful living constructor of telescopes is an American — Alvan Clark of Cambridge, Massachusetts.”



The 26-inch sits in the USNO’s original Foggy Bottom location with the original Clark tube and mount. Simon Newcomb is at the eyepiece; sitting in the back is the USNO’s then-superintendent, Commodore Benjamin Sands. USNO

Five years later, the USNO was rewarded with the most powerful instrument that the renowned Alvan Clark & Sons firm had ever built.

This year, that 26-inch refractor turns 150 years old. When it was completed in 1873, it was the world’s largest telescope, vaulting the USNO back into the ranks of elite observatories. But what is perhaps most remarkable about this telescope is its longevity. Unlike so many other great telescopes of its era, the USNO 26-inch has remained a scientific workhorse well into the age of space exploration and digital imaging, building on its legacy even today.

The craftsman

Alvan Clark was an inventor, portrait painter, and self-taught optician. In the 1850s, he and his two sons had a machine shop in Cambridgeport, Massachusetts. Alvan Clark & Sons took on all sorts of machining jobs, but their true passion was constructing telescopes and grinding and polishing lenses.

Unfortunately, they were not getting much work for astronomy. Their tools were crude, and Boston’s academic elite looked down on Clark’s lack of formal training. But Clark’s exceptional eye and craftsmanship came to light after he struck up correspondence with British astronomer William Rutter Dawes, an expert on double stars. Clark told Dawes of pairs

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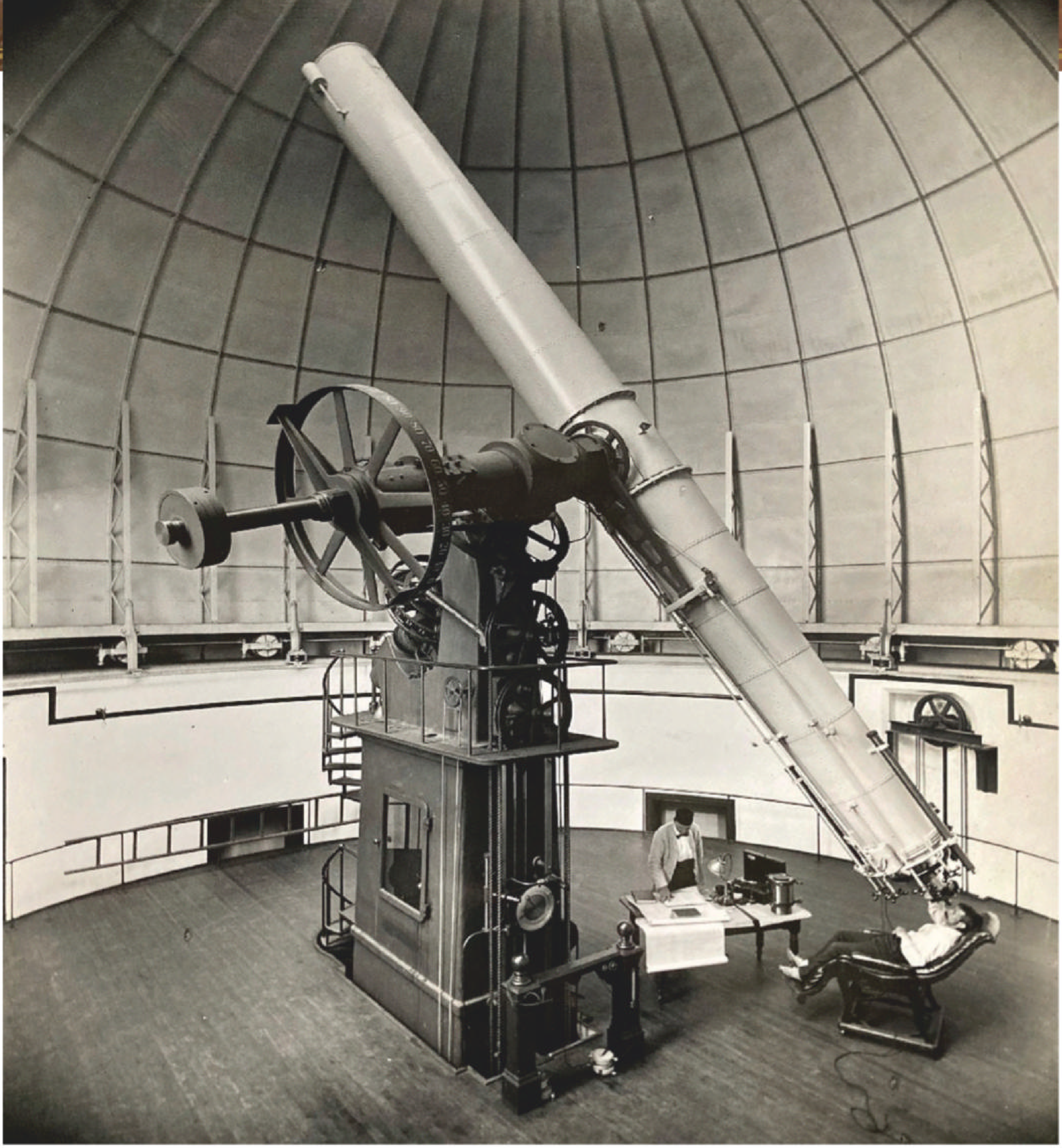


Astronomer Stimson Brown observes at the 26-inch shortly after it was remounted at the USNO's Georgetown Heights campus. USNO LIBRARY

he had been able to split with his telescopes. An impressed Dawes gave him more targets to attempt and commissioned a 7.5-inch refractor from him.

In 1857 in *Monthly Notices of the Royal Astronomical Society*, Clark and Dawes reported a slew of new double stars — many of which had previously gone undetected by much larger telescopes. Dawes raved about Clark's discoveries, calling them by turns "truly astonishing," "almost startling," and demonstrations of what "may be achieved by a diligent use of instruments of moderate dimensions, provided they are also of extreme perfection."

It was the recognition the Clarks needed: Soon after, they turned their business wholly over to telescopes and optics, and orders began to pour in — especially after they built the 18.5-inch Dearborn scope and discovered the long-predicted companion to Sirius, the white dwarf known as Sirius B.

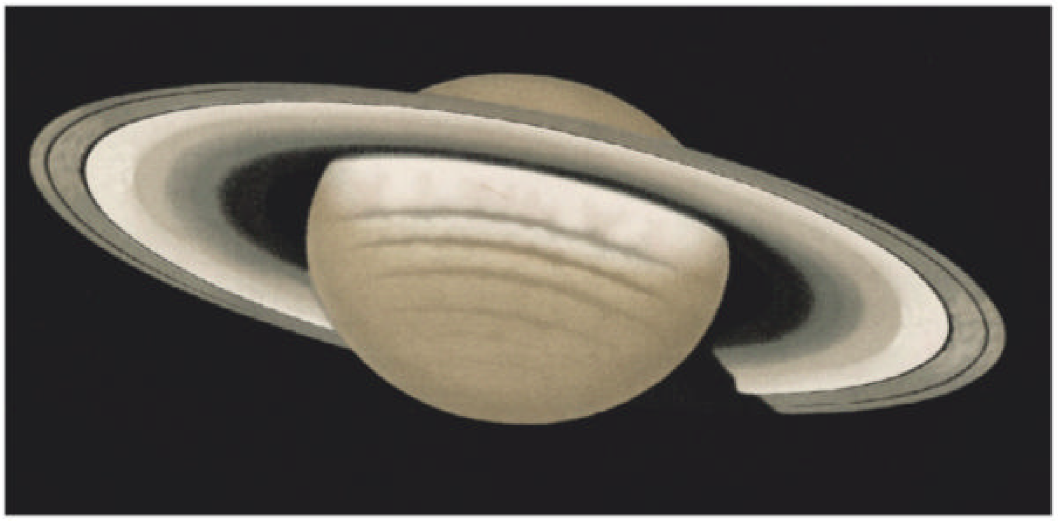
By 1868, word had gotten round that Clark wanted to build the largest telescope in the world, but was waiting for a client who could afford the price tag of $40,000 in gold. The USNO's Benjamin Sands suggested the buyer should be Uncle Sam. Invoking patriotic pride, he wrote, "it seems eminently desirable and proper that the government of the United States should employ at its observatory such an instrument of the highest power.” But his request was denied.

It wasn’t until 1870 that the USNO broke through D.C.’s insider politics. The opportunity came when Cyrus Field, the financier behind the first transatlantic telegraph cable, visited Washington and hosted a dinner with senators Hannibal Hamlin of Maine and Eugene Casserly of California. In conversation, Field’s son was asked what he had done in Washington. He said he had visited the USNO, and he remarked on the small size of their telescope. Incredulous, the senators promised swift redress. Funding for the 26-inch was approved in July 1870 — $55,000 for the telescope, dome, and pier.

By October 1872, Clark had finished grinding and polishing the lens, which consisted of a 70-pound (32 kilogram) crown-glass element and a 110-pound (50 kg) flint-glass element finely separated by 0.029 inches (0.74 millimeters). In October 1873, Clark & Sons delivered and installed the telescope. The tube was placed in a harp-shaped mount based on a design by Simon Newcomb, a senior astronomer at the USNO. The telescope, installed at the observatory’s Foggy Bottom site in Washington, D.C., included two finders, periscopes for reading right ascension and declination, micrometers, and a spectroscope. The wooden dome was plated with galvanized iron; the observing slit was covered with surplus sailcloth.

THE ERA OF THE GREAT REFRACTORS

HISTORICALLY, REFRACTING TELESCOPES were limited in size due to aberrations. The first large telescope to correct for this was the 9.6-inch Great Dorpat Refractor in Tartu, in modern-day Estonia. Constructed in 1824 by Joseph Fraunhofer, it was used by German astronomer Friedrich Georg Wilhelm von Struve. What followed was a technology contest throughout the 19th century to build the largest telescope — the era of what we now call the great refractors. Telescopes built by Alvan Clark & Sons held the top spot five different times, and the USNO’s 26-inch was the largest in the world from 1873 to 1880. *—B.D.M.*



Étienne Léopold Trouvelot’s pastel drawings based on his observations with the 26-inch in late 1875 (like this rendering of Saturn) revealed details that photography was not yet capable of capturing. USNO LIBRARY

Newcomb’s first look through the telescope left him profoundly moved. “I was filled with the consciousness that I was looking at the stars through the most powerful telescope that had ever been pointed at the heavens, and wondered what mysteries might be unfolded,” he later wrote. “The night was of the finest, and I remember, sweeping at random, I ran upon what seemed to be a little cluster of stars, so small and faint that it could scarcely have been seen in a smaller instrument.”

Weighing the solar system

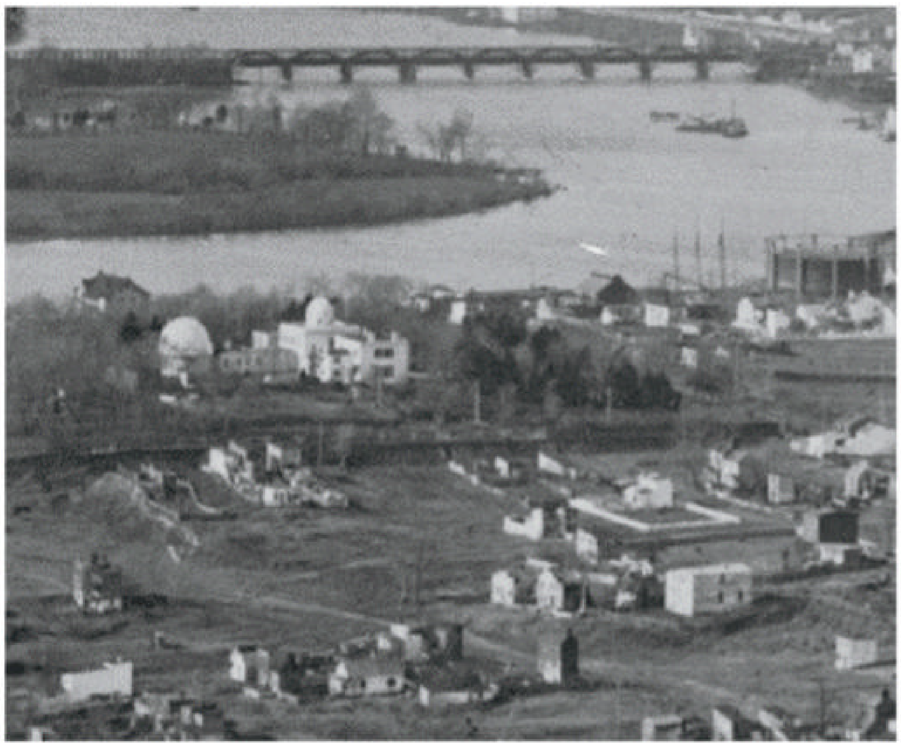
The newly minted telescope was quickly put to its first “great work,” as Newcomb called it — observing the moons of the outer planets. This was key to the main scientific justification for the 26-inch: investigating the errors in the position of Jupiter and Saturn. These two beacons of the night sky had long been important objects for celestial navigation, but astronomers had realized that their motions were being perturbed by the gravitational influence of Uranus and Neptune. Thus, the masses of the outer planets were important to Newcomb’s models of the solar system. And the best way to measure the masses of Uranus and Neptune was to observe the motions of their moons.

Regular operations with the 26-inch commenced Nov. 20, 1873, with observations of Neptune’s moon Triton and the four then-known moons of Uranus. Here, the scope could show its power: It was large enough to see moons as faint as magnitude 14, and its very long focal length allowed it to accurately determine their motions. Observations of the satellites of the outer planets featured in the telescope’s first publications, authored by Newcomb and his associate, Edward S. Holden. Remarkably, the 26-inch continued this observing program for over 100 years.

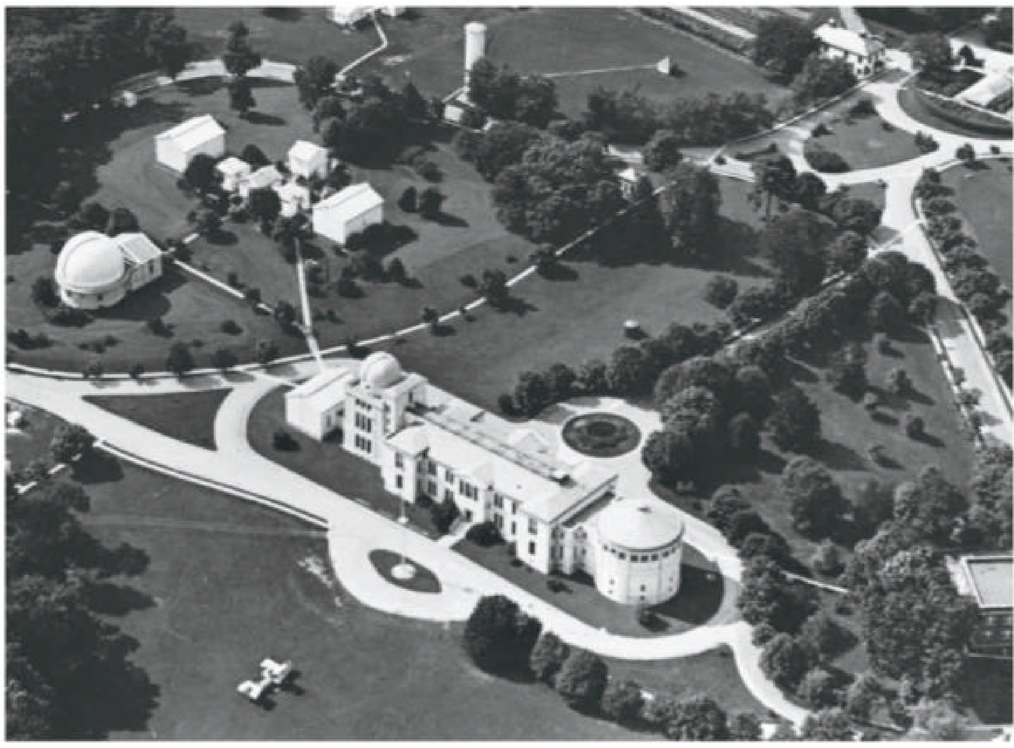
But while Newcomb was keen on improving his models, he was not an industrious observer. In 1875, he turned over operation of the 26-inch to Asaph Hall, who had joined the USNO 13 years earlier. By contrast, Hall was a prodigious observer and published over 1,700 double-star measurements. Considering each published measurement was the average of many repeated measurements, he may have made over 20,000 individual measurements.

The 26-inch also made a splash with the public. At the invitation of the USNO superintendent, the French artist Étienne Léopold Trouvelot looked through the 26-inch in late 1875 and made a series of pastel drawings, including Saturn, the Omega Nebula (M17), and the Orion Nebula (M42). These were exhibited at the U.S. Centennial Exhibition in 1876. Before advances in photography, they were the best available representations of objects in the night sky — the era’s equivalent of images from the Hubble or James Webb space telescopes.

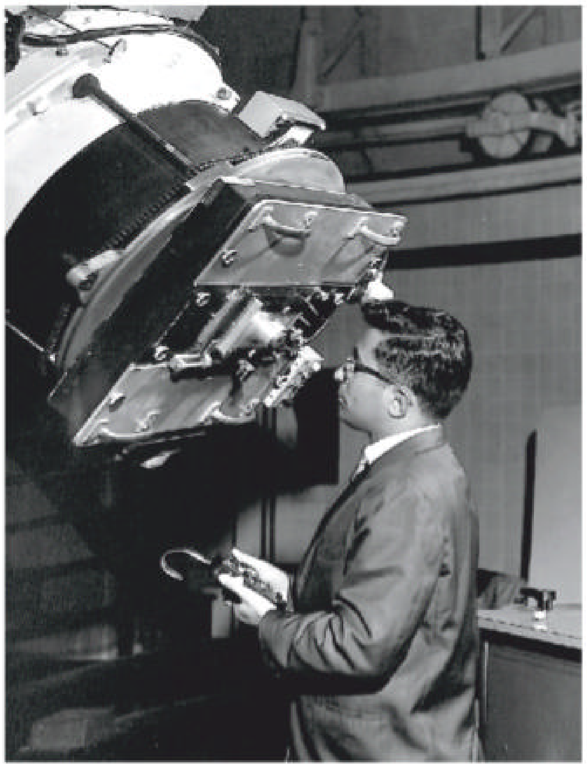
But the most famous discovery in the history of the 26-inch occurred



The USNO's original Foggy Bottom building (center left) was within sight of the Potomac, as seen in this view from the top of the Washington Monument in 1885. On top of the building is the dome of the 9.6-inch refractor; this was topped by a mast and a time ball, which dropped at noon every day so sailors could set their chronometers. The dome of the 26-inch is at left. These single monolithic observatory structures, housing all instruments and offices, were the standard observatory construction technique at the time. USNO LIBRARY



When the USNO's Georgetown Heights campus was built, observatories had gone through a renaissance in design, evident in this aerial view from the 1920s. Instead of a single building, observatories were now parklike campuses with separate structures for each instrument to better control their environment. NAVAL HISTORY AND HERITAGE COMMAND



USNO astronomer Mihran Miranian centers a target in the photographic double star camera prior to installing the photographic plate and beginning a series of observations, in this picture taken in the mid-1970s. USNO LIBRARY

only four years after first light, when Hall turned the 26-inch to look at Mars during a close approach. At the time, no moons had yet been discovered around the Red Planet. Distrusting Holden, whom he saw as something of a spy for Newcomb, Hall waited until he wasn't around and then swung the telescope to Mars to go moon hunting.

Late on the night of Aug. 11, 1877, Hall saw a faint object which later proved to be Deimos. But conditions prevented follow-up observations for four nights. Finally, on Aug. 16, the skies cleared and he was able to re-observe Deimos, as well as spot a now closer and brighter moon, Phobos, and verify they were moving with the planet and not mere background stars. The news of the discovery appeared in newspapers all over the world.

But within the USNO, it also was the source of more friction and misunderstanding between Hall and Newcomb. In Hall's initial descriptions, he was modest and cautious about the finds — which led Newcomb to think Hall didn't realize they were moons of Mars. Hall thought Newcomb was trying to take credit and steal his discovery. But luckily, they were able to resolve their differences later in life.

Fleeing the swamp

Unfortunately, Foggy Bottom wasn't merely a name, but a condition. Fog frequently rolled in off the Potomac, reducing the output of all telescopes at the USNO. In 1877, 168 nights were too cloudy for observing, and 133 were poor; only 21 nights were recorded as good or very good. Indeed, surrounded by a swamp to the south, coal gas works to the west, and an open sewer to the east, conditions were rarely good for anything except breeding mosquitoes: The superintendents, their families, and staff astronomers all suffered from malaria.

By late 1877, they were looking for a new site, and maintenance of the existing facility languished. When the USNO finally began construction on a new location in the hills above Georgetown in the late 1880s, they took advantage of the opportunity to upgrade the 26-inch. The Warner & Swasey Company reinstalled the Clark doublet in a 14-section tube and made a new, more robust mount, pier, and dome. And a new 15-ton boiler-powered elevating floor eliminated the need to clamber up a ladder to use the telescope; instead, the floor lifted the observer to the eyepiece. The 26-inch resumed operation when the USNO opened its new site in 1893.

About 50 years after the discovery of Mars' moons, the 26-inch played a key role in another significant discovery about Phobos. In the 1920s, Harry Burton, using the 26-inch, thought he might have detected that Phobos was accelerating in its orbit, indicating it was spiraling inward towards Mars.

Bevan Sharpless made similar observations in 1939 and 1941 with the 40-inch reflector, and in 1945, he published his results confirming that Phobos is indeed doomed — getting closer and closer to Mars at the rate of roughly 0.8 inch (2 centimeters) per year.

After Burton's retirement, the planetary program wound down until 1967 when, in support of NASA's mission planning, Dan Pascu began observing once more the satellites of Mars and the outer planets using the 26-inch. These observations eventually supported NASA's Voyager 1 and 2 probes that ventured to the outer solar system and beyond.

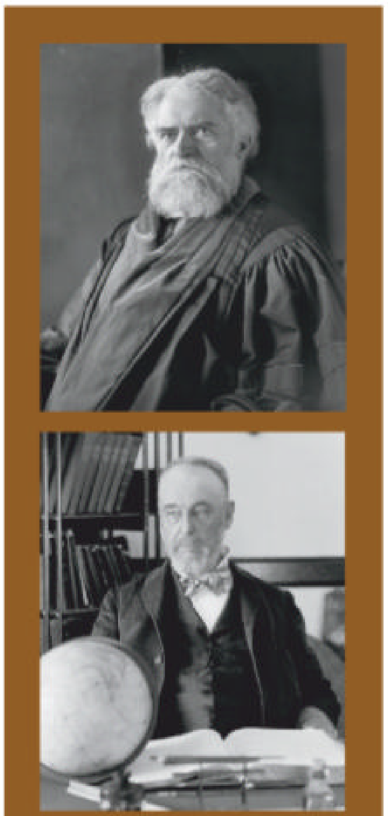
The dome of the U.S. Naval Observatory's 26-inch refractor sits in the hills overlooking the Georgetown neighborhood of Washington, D.C. NAVAL METEOROLOGY AND OCEANOGRAPHY COMMAND

Double stars

The other great work of the 26-inch's illustrious career has been its observations of double stars. In fact, the first orders to Matthew Fontaine Maury, the first superintendent of the USNO, in 1846 specifically mentioned the need to observe double stars. But in the telescope's early history, this took a back seat to solar system work.

Other than the work of Hall, the 26-inch contributed few double star observations until nearly the 1960s, when Kaj Strand came to the USNO. Strand, who became the observatory's scientific director in 1963, had been trained by Ejnar Hertzsprung in the use of photography for measuring doubles.

Shortly thereafter, at a meeting of the double- and multiple-star division of the International Astronomical Union in Hamburg, Germany, Lick Observatory announced it wished to divest itself of the responsibility for maintaining the IAU's double star database, the Index Catalog of Visual Double Stars (IDS). Strand volunteered the USNO for this task and in August 1964, the IDS was transferred to the USNO and renamed the Washington Double Star Catalog (WDS).



Simon Newcomb (top) and Asaph Hall (bottom) were both hired by James Gillis, the USNO superintendent who designed the observatory's Foggy Bottom building. FROM TOP: LIBRARY OF CONGRESS; USNO

Charles Worley, a former member of Lick's staff, was tasked with maintaining it. After the tailpiece of the 26-inch was modified to accommodate the photographic double-star camera in 1958, the telescope began a new era, with an emphasis on double stars that continues to this day.

Worley and the 26-inch continued to evolve their techniques. In 1981, the photographic program ended. But filar micrometry, in which an observer uses an eyepiece with a reticle to measure the separation of a double star, continued. Worley was particularly skilled at this art, which had been used on the 26-inch since 1873. But in the twilight of his career, he abandoned it for the superior technique of speckle interferometry, which extracts information from the small spots or "speckles" that appear around an image of a star due to interference effects caused by atmospheric turbulence. In a 1987 interview, 10 years before his death, he quipped, "I'm the last generation of visual observers, and I should be the last generation of visual observers. I think it's time to do this kind of astronomy in different ways."

Speckle observations of double stars continue on the 26-inch to this day. The USNO's first speckle camera, with an intensified CCD detector, was installed in 1990; in 2019, it was retired in favor of a newer, more advanced electron-multiplying CCD.

As a result, in terms of total number of measured relative positions, the 26-inch is the most productive telescope for double-star astronomy ever. The WDS is legendary in the field and remains the gold standard for double-star catalogs: As of August 2022, it contained over 155,000 double stars.

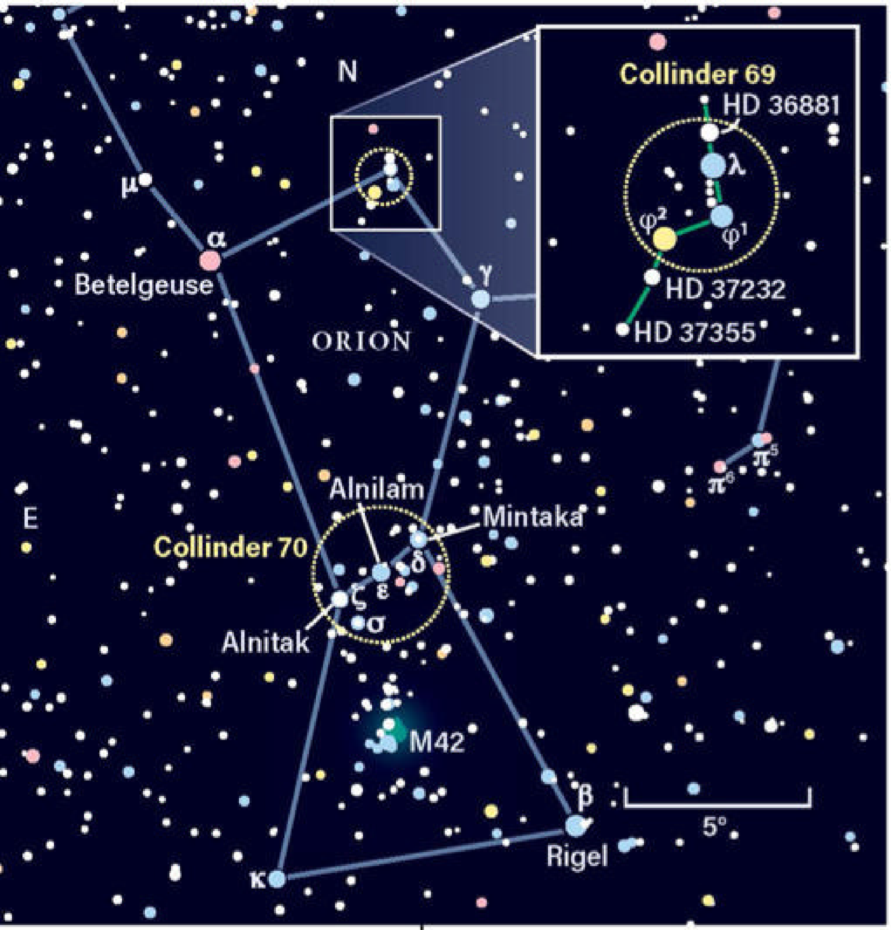
After a century and a half, the venerable 26-inch shows no signs of giving out or letting up. As Worley said in 1988: "The truth of the matter is that this is often rather a good climate, as far as the steadiness of the atmosphere goes, so I think the telescope has the potential of continuing to produce good astronomical observations."

Happy birthday, telescope!

Brian D. Mason *is an astronomer at the U.S. Naval Observatory, specializing in double-star observing and research.*

Orion's hidden treasures

Scour the sky for some new prey.



Take a seat, kick your feet up, and enjoy some of the more overlooked targets the Hunter has to offer. *ASTRONOMY*: ROEN KELLY

BY PHIL HARRINGTON

Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

Without a question, Orion the Hunter tops the list when it comes to renowned constellations. The reason is simple: Orion demands our attention because it is visible around the globe this time of year. Its brightest stars — Betelgeuse (Alpha [α] Orionis) and Rigel (Beta [β] Orionis) — are discernible in all but the severest light polluted skies. And, visible through binoculars and telescopes, the Hunter hosts one of the sky's most famous sights: the Orion Nebula (M42).

But there is much more to see within Orion than these familiar gems. This month, we are going to hunt for some of the Hunter's lesser-known targets.

This month, we are going to hunt for some of the Hunter's lesser-known targets.

Raise your binoculars toward Orion's Belt. The three equally spaced stars that form the Belt are, from west to east, Mintaka (Delta [δ] Orionis), Alnilam (Epsilon [ε] Orionis), and Alnitak (Zeta [ζ] Orionis). These stellar belt loops are among the hottest stars visible to the unaided eye.

As you view the scene through your binoculars, notice how the many fainter stars that surround the Belt appear to form a football-shaped pattern parallel to the Belt. An S-shaped asterism of a dozen stars winds its way from Mintaka to Alnilam; if we imagine those dim stars as a football, maybe the S is its stitching.

Centered on Alnilam is a collection of more than 70 stars belonging to **Collinder 70**. The Collinder catalog, published in 1931 by Swedish astronomer Per Collinder, includes 471 open clusters. Some are cross listed in the Messier and NGC catalogs, while others, like Collinder 70, are not.

Collinder 70 contains more than 100 widely separated stars. For instance, Mintaka and Alnitak are estimated to lie some 900 and 800 light-years away, respectively, but Alnilam is another 400 or so light-years farther out. The stars in Collinder 70 belong to the Orion OB1 association. OB associations are loose collections of young, hot, type O and B stars often separated by tens or hundreds of light-years.

Another member of the Collinder catalog lies north of Collinder 70. **Collinder 69** overlays Orion's tiny triangular head, so it is also easy to locate. Some references call it the Lambda (λ) Orionis Cluster, since third-magnitude Lambda, also known as Meissa, is the brightest member.

Long before it was recognized as a cluster, Orion's head drew attention. In his 1888 book *Astronomy With an Opera-Glass*, Garrett P. Serviss wrote, "Although there is no nebula here, yet these stars, as seen with the naked eye, have a remarkably nebulous look."

Binoculars resolve Collinder 69 into a scattered collection of about 20 stars strewn across 70'. Three stars stand out in the field. Their equal spacing and similar brightness remind me of a miniaturized Orion's Belt. At the center is Lambda, while Phi^1 (φ^1) sits to its south and 6th-magnitude HD 36881 lies to its north. The southeastern star in Orion's head, Phi^2 (φ^2) Orionis, is not a cluster member.

Serviss noted a faint glimmering between Lambda and Phi^1. He explained how "a field-glass shows that this twinkling is produced by a pretty little row of three stars of the eighth and ninth magnitudes."

Serviss was wrong about one thing, however, when he said there is no nebula here. He would be amazed to learn that the entire area is engulfed in a huge glowing cloud of gas and dust cataloged as Sharpless 2–264. Although invisible through binoculars, it appears as a large sphere of ionized hydrogen in images.

Expand the scene to include Phi^2, as well as stars HD 37232 and HD 37355 to its southeast, and you get an asterism that looks like a **Recliner**. That's how reader Hope Harle-Mould near Buffalo, New York, interprets it. HD 36881 and Phi^1 form the back, while Phi^1 to Phi^2 and those other two HDs make the seat and leg extension. So, kick up your feet and see if you can also imagine a comfy chair here.

Next month, we'll head south for a late winter getaway. Questions, comments, suggestions are always welcome. Contact me through my website, philharrington.net. Until next time, remember that two eyes are better than one.

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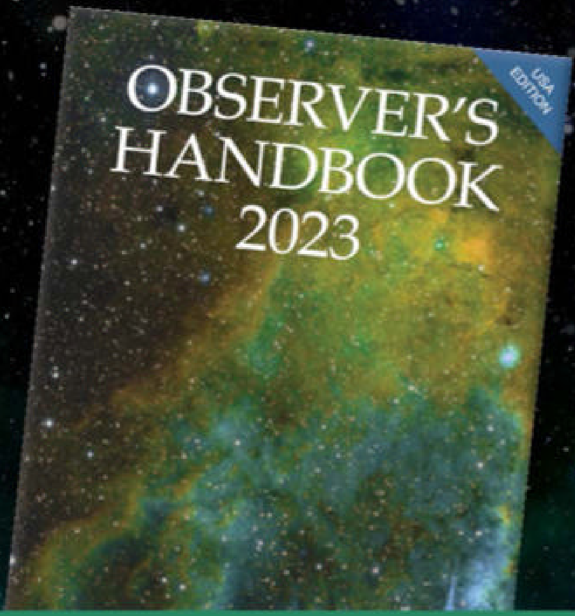
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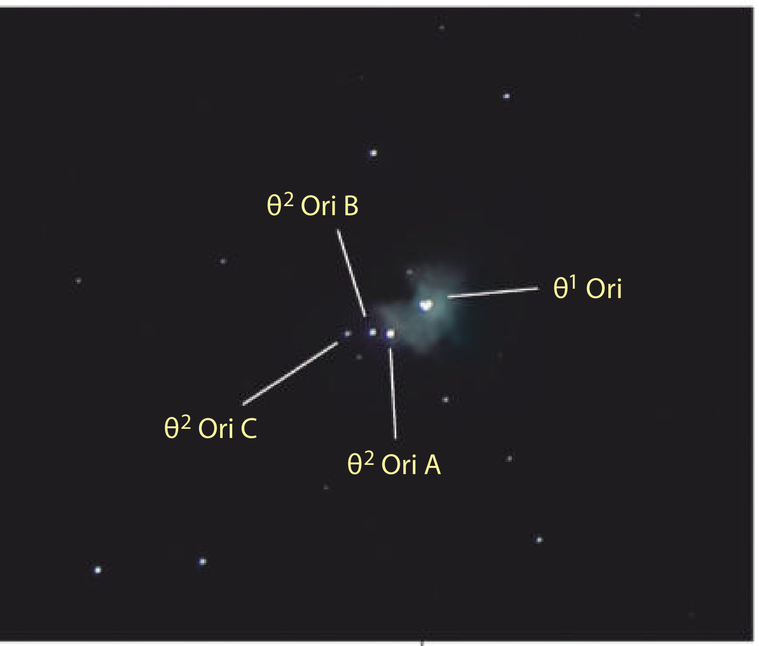
The Theta Orionis challenge

This multiple-star system will test your visual acuity.



To the naked eye, Theta^1 Orionis is the combined light of the four main stars of the Trapezium star cluster in M42. Theta^2 Orionis A and B (only about 1' apart) also combine to form one star as seen with the unaided eyes. The separation between Theta^1 and Theta^2 A is 2.2'. STEPHEN JAMES O'MEARA

BY STEPHEN JAMES O'MEARA

Stephen is a globe-trotting observer who is always looking for the next great celestial event.

Up for an *extreme* challenge? One with your unaided eyes? If so, buckle up for this one: splitting Theta^1 (θ^1) Orionis and Theta^2 (θ^2) Orionis without optical aid. For some, this challenge may be "out of sight," but there's only one way to find out.

First, some background

Theta^1 and Theta^2 Orionis are two multiple-star systems within the Orion Nebula (M42). Theta^1 includes several stars; the four brightest comprise the Trapezium star cluster at the heart of M42. To the unaided eye, these four stars shine roughly as a solitary 5th-magnitude star. The magnitude is not exact, because the Trapezium's two brightest components (Theta^1 Orionis A and B) are eclipsing binary stars. Theta^1 Orionis A dips in brightness by 1 magnitude every 65 days in an eclipse lasting over 20 hours; Theta^1 Orionis B dips in brightness by 1 magnitude every 6.5 days over 16 hours. So, you're likely to catch the Trapezium stars when they are close to their brightest, but it's not guaranteed.

Theta^2 Orionis A shines at magnitude 5.0 but, to the unaided eye, its light combines with neighboring Theta^2 Orionis B (magnitude 6.2 and about 1' away), giving it an extra visual kick. (Theta^2 Ori C, the other component of Theta^2 Ori, is below naked-eye visibility at 8th magnitude.) So, in essence, the challenge involves separating two 5th-magnitude multiple stars 2.2' apart. That's a tiny gap. Most people find splitting the famous Double Double in Lyra a challenge; its two 4th-magnitude companions are wider apart (3.5') and 0.5 magnitude brighter than the Theta stars.

That's a tiny gap.

What's more, anyone trying to split Orion's Theta stars under a dark sky will discover a visual impediment: the surrounding Orion Nebula, whose glow lowers the contrast of the gap between the two stars.

The Theta challenge

Scott Harrington of Evening Shade, Arkansas, brought the unaided Theta challenge to my attention after he succeeded in splitting the pair. He writes in an email, "I doubt I could ever do any pair of stars that are closer together with the naked eye."

Orion Nebula

The Great Orion Nebula (M42, the middle "star" in Orion's Sword) is the site of this month's naked-eye challenge. STEPHEN JAMES O'MEARA

Harrington had known for some time that his friend Lauren Herrington had already resolved the Thetas with her unaided eyes. But he hadn't been able to do it under his rural country skies, finding that the surrounding nebula completely overpowered the stars. In January 2022, however, he found the nebula greatly diminished under the light of the Full Moon and tried again. Using a chimney to block the Moon, he saw the two Theta stars strongly elongated and "for moments I could split them," he writes.

Herrington's observation is especially revealing and speaks volumes about her visual acuity. "I've never really been able to see the Orion Nebula with the naked eye," she writes, "even from very dark skies. All I can see is the double star of Theta Orionis, which is well separated (a little dark lane in the middle). I've often noticed it because the canted double of Theta makes a fun pair with the wider and brighter double of Iota (ι) Orionis just to the south." Her confidence is refreshing.

Direct versus averted vision

Seeing and resolving the Theta pair requires a tricky trade-off between averted and direct vision. It's easiest to resolve double stars when looking at them directly and intently, but your eye will be less sensitive to their light than with averted vision and may lose sight of them entirely. In his *The Nature of Light and Color in the Open Air*, the late Dutch astronomer Marcel Minnaert wrote, "To me personally, even the stars of the fourth magnitude become invisible, whereas those of the third magnitude remain visible."

While this limit may vary from observer to observer, it shows the difficulty of the task ahead, especially if you live under a dark sky where the nebula interferes. But dark-sky observers don't have to wait for a Full Moon — a First Quarter Moon is better, as it not only adequately diminishes the nebula's light but also allows the dim Theta stars to shine through more conspicuously.

You can also wait for the Theta stars to emerge from twilight's last gleaming (largely nebula-free) and follow them until nightfall. Twilight is, and always has been, the best time to separate multiple stars. Good luck, and, as always, let me know how you fare at someara31@gmail.com.

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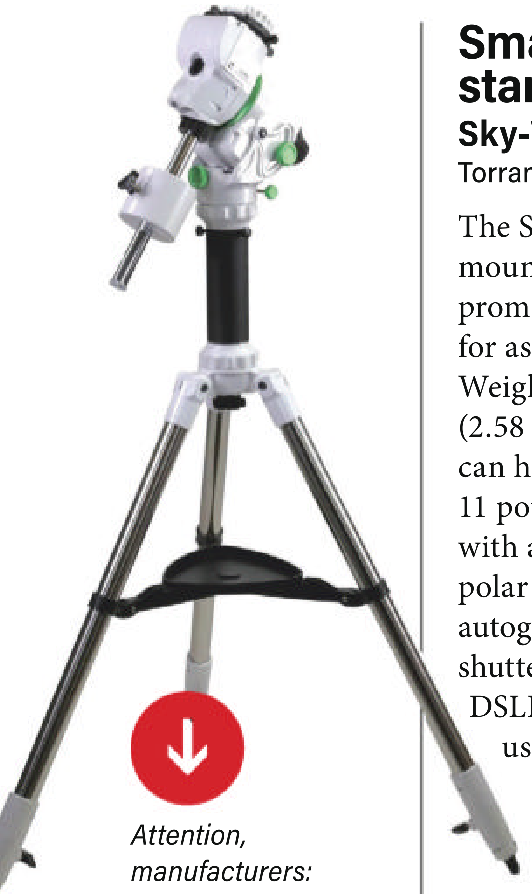

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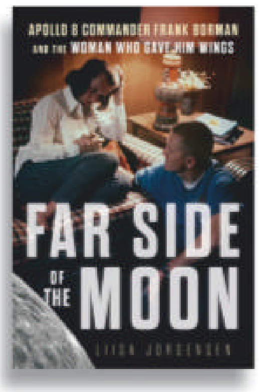
APOLLO 8 COMMANDER FRANK BORMAN AND THE WOMAN WHO GAVE HIM WINGS
FAR SIDE OF THE MOON
LIISA JORGENSEN

When Apollo 8 became the first manned spacecraft to orbit the Moon, the public was captivated by the men who accomplished the feat, including spacecraft commander Frank Borman. But back on Earth, his wife Susan struggled to maintain the perfect image as an astronaut's spouse. In *Far Side of the Moon*, author Liisa Jorgensen tells the story of Apollo 8 through the eyes of the woman left behind as her husband ventured into space.

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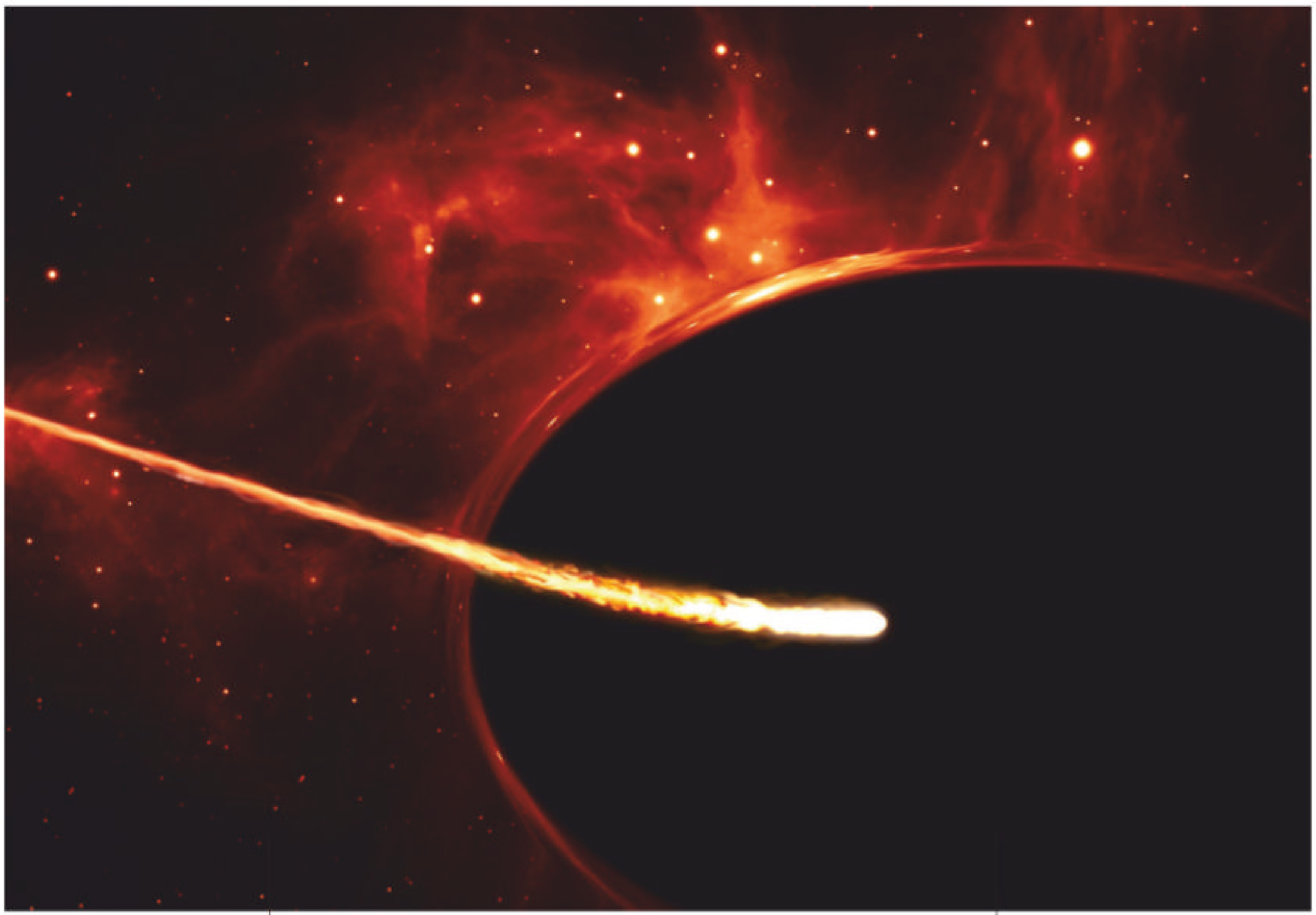


Even though a human falling into a supermassive black hole wouldn't be spaghettified, a star still experiences tidal forces as it falls into a black hole, as shown in this artist's concept. ESO, ESA/HUBBLE, M. KORNMESSER

Relaxing fall

Q | WHY WOULD SOMEONE FALLING INTO A STELLAR-MASS BLACK HOLE BE SPAGHETTIFIED, BUT SOMEONE CROSSING THE EVENT HORIZON OF A SUPERMASSIVE BLACK HOLE WOULD NOT FEEL MUCH DISCOMFORT?

Robert Walty
Stephens City, Virginia

A | First, what exactly causes spaghettification? This process is the result of tidal forces, or the difference in gravity between two points.

As it turns out, there is a relatively simple equation that describes the tidal acceleration that a body of length **d** would feel, based on its distance from a given object with mass **M**: $a = 2GMd/R^3$, where **a** is the tidal acceleration, **G** is the gravitational constant, and **R** is the body's distance to the center of the object (with mass **M**).

For a baseline, let's calculate the tidal acceleration that an approximately 6-foot-tall (1.8 meters) person feels between their head and their feet while on the surface of Earth. Plugging in the numbers, it comes out to about 0.0000055 meter/second^2. Now, how would tidal forces affect that same person falling into a stellar-mass black hole of 1 solar mass and an event horizon radius of 1.8 miles (2.9 kilometers), versus that same person falling into a supermassive black hole that is 100 million solar masses with an event horizon radius of 183 million miles (295 million km)?

In the former case, the tidal acceleration is around 19.6 billion m/s^2. And for the supermassive black hole, it's only about 0.0000019 m/s^2.

So, for a person falling feet first into a stellar-mass black hole, the tidal forces stretch them out into a long, thin line resembling spaghetti. But when falling into a supermassive black hole, the tidal acceleration they feel is even smaller than what we experience on Earth!

Caitlyn Buongiorno
Associate Editor

Q | MANY YEARS AGO, WE VIEWED A TOTAL ECLIPSE, AND I REMEMBER JUST BEFORE THE ONSET OF TOTALITY, WE SAW BANDS OF LIGHT AND DARK SHADOWS RACING ACROSS THE GROUND. WHAT IS THE EXPLANATION FOR THIS?

Gerald Baseden
Wilmington, Delaware

Artificially highlighted in this image, faint shadow bands on the ground can be difficult to spot. STEPHEN JAMES O'MEARA

A These bands of light and dark, coincidentally enough, are called shadow bands. Because they are so fleeting and subtle, only appearing for a few seconds before or after totality, they tend to be hard to catch — so it's quite exciting that you saw them!

Scientists believe shadow bands arise because of the turbulent nature of Earth's atmosphere. As the Moon moves to fully cover the Sun or just begins to slide away as totality ends, only a tiny crescent of the solar disk is visible. Refraction of this bright, thin light source through our atmosphere creates the pattern of light and dark lines, and the motion of the air makes them ripple and move. As the atmosphere is constantly changing, they are both short-lived and impossible to predict.

To increase your chances of viewing this phenomenon, consider spreading out a light-colored sheet or large piece of paper on the ground before an eclipse. The light, flat surface can help highlight the shadow bands if they occur. Because shadow bands only appear right before or after totality — when you may want to focus on the main attraction — you can also train a video camera at the sheet or paper so you don't have to worry about splitting your attention.

Alison Klesman
Senior Editor

Q | WILL PLUTO AND NEPTUNE EVER COLLIDE?

Tom Knize
St. Louis, Missouri

A With Pluto spending 20 years of its 248-year orbit within the orbit of Neptune, you might expect that at some point, the two worlds could catastrophically collide. However, Pluto and Neptune never actually pass through the same three-dimensional point in space because Pluto's elliptical orbit is tilted 17° to the ecliptic. But what about in the future?

Pluto's orbit experiences two effects that keep the dwarf planet safe: Its point of closest approach to the Sun oscillates in the vertical direction and also in the radial direction. These orbital effects are called latitudinal libration and azimuthal libration, respectively.

Latitudinal libration always puts Pluto high above Neptune's orbit during their closest approach to each other. And azimuthal libration ensures Pluto never crosses Neptune's orbit within 90° of the ice giant.

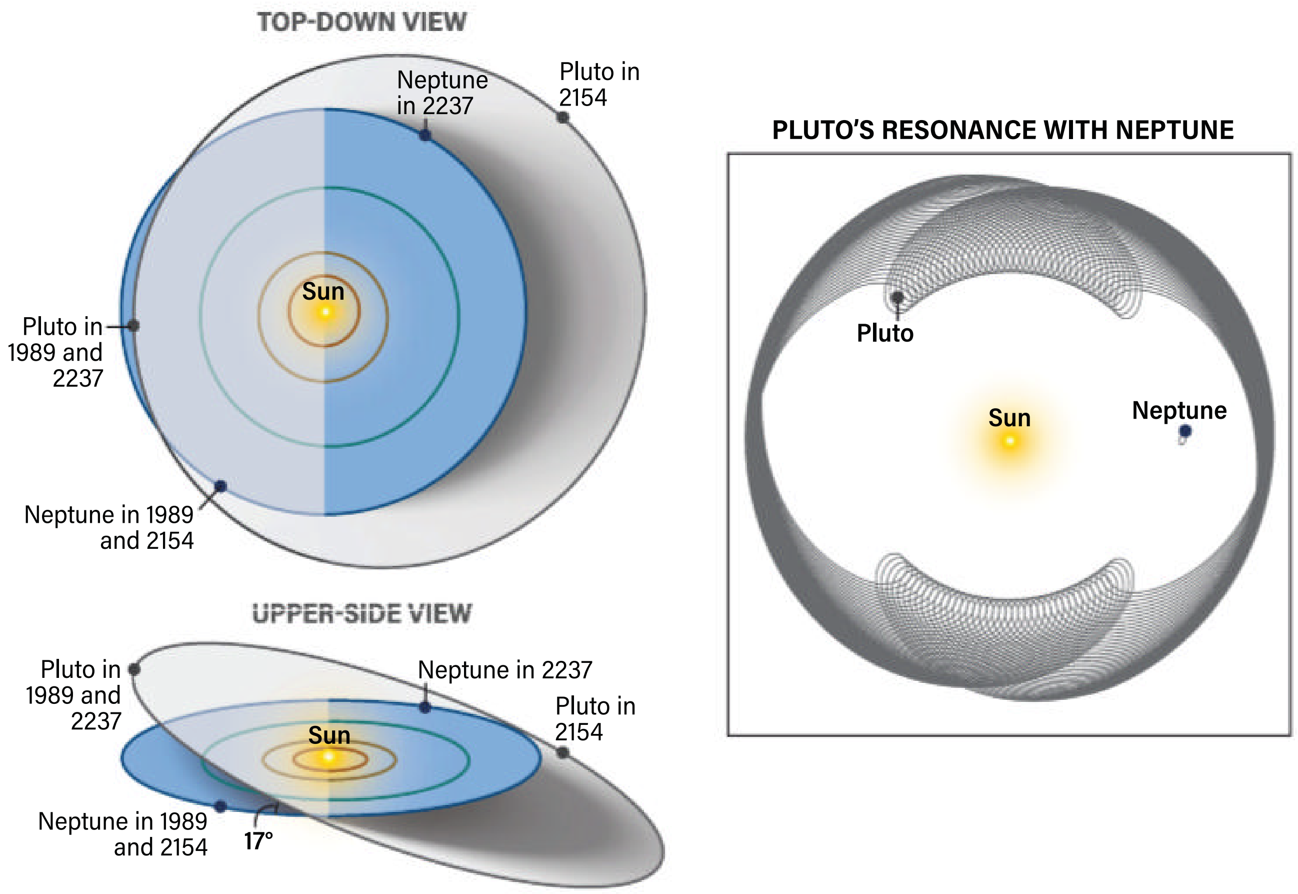
These properties are a consequence of a so-called orbital resonance between the two worlds. Pluto and Neptune are locked in a 3:2 orbital resonance, which means that for every three trips Neptune makes around the Sun, Pluto orbits twice. If they start getting out of sync, their mutual gravitational pull nudges them back into a finely choreographed dance. As a result, Pluto and Neptune never come within about 16 astronomical units (where 1 astronomical unit is the average Earth-Sun distance) of one another.

Despite this, in the late 1980s, numerical simulations suggested that Pluto's orbit is technically chaotic: Over the course of several billion years, Pluto should either collide with another world or be ejected from the solar system entirely. However, in a recent paper titled "Pluto near the edge of chaos," published March 31, 2022, in *Proceedings of the National Academy of Sciences*, researchers explored why Pluto's orbit ultimately has remained stable over the solar system's lifetime.

To do this, they ran a series of simulations of the outer solar system that tracked the evolution of Pluto's orbit over about 4.5 billion years. The researchers found that, somewhat surprisingly, Uranus seems to push the dwarf planet toward a chaotic orbit. But while Neptune provided the greatest contribution to stabilizing Pluto's azimuthal libration, the giant planet did not significantly influence the strength of Pluto's latitudinal libration. Instead, Jupiter seemed most responsible for this particular collision-avoidance feature of Pluto's orbit. So, as long as our solar system maintains the orbital status quo, we shouldn't expect any planetary fireworks.

Jake Parks
Digital Editor

PLUTO'S WEIRD ORBIT

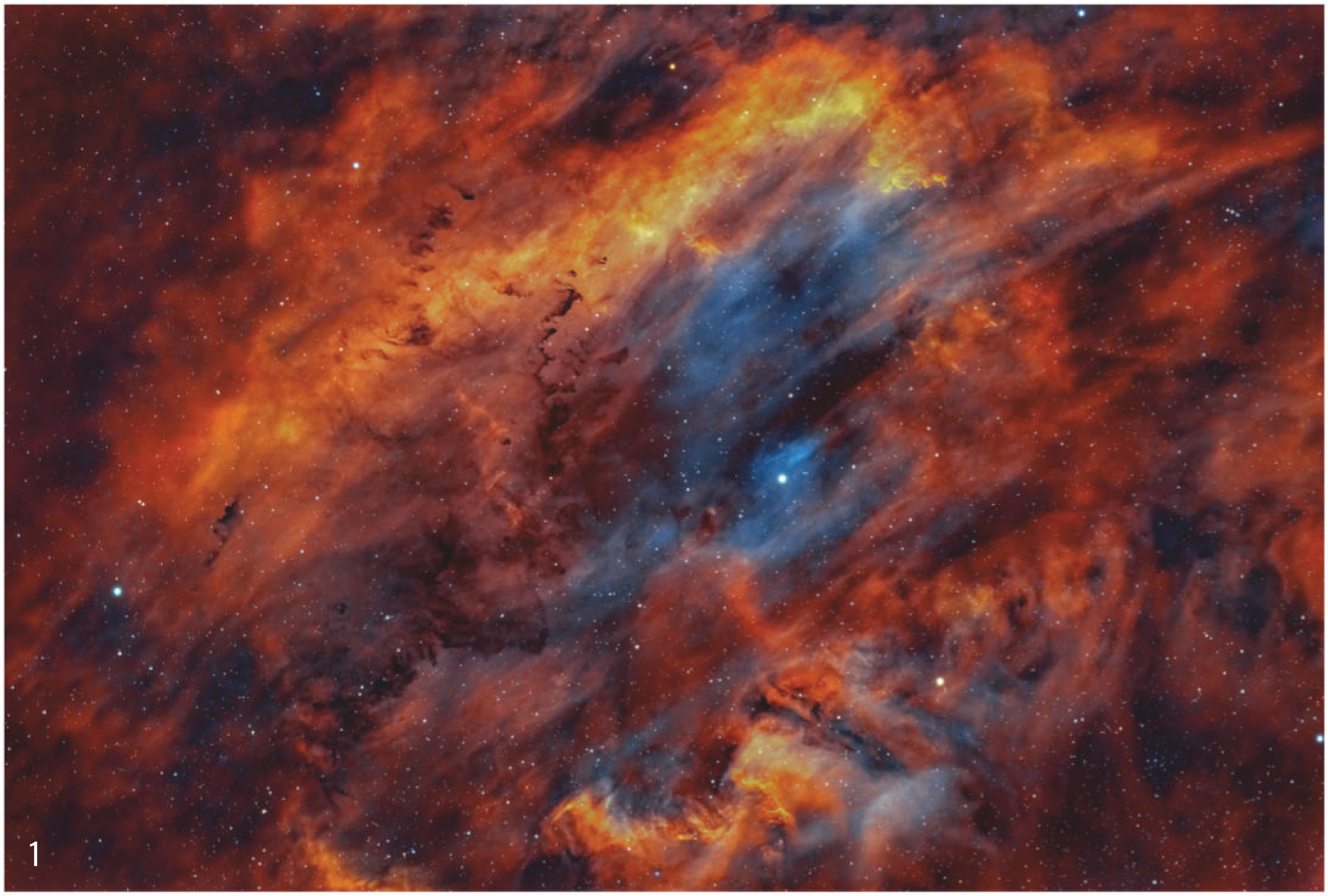


While in two-dimensional space it may appear that Neptune and Pluto's orbits intersect, the planets are, in fact, never in the same place at the same time. This is a result of their 3:2 orbital resonance, which limits the minimum distance between the worlds. *ASTRONOMY:* ROEN KELLY

SEND US YOUR QUESTIONS

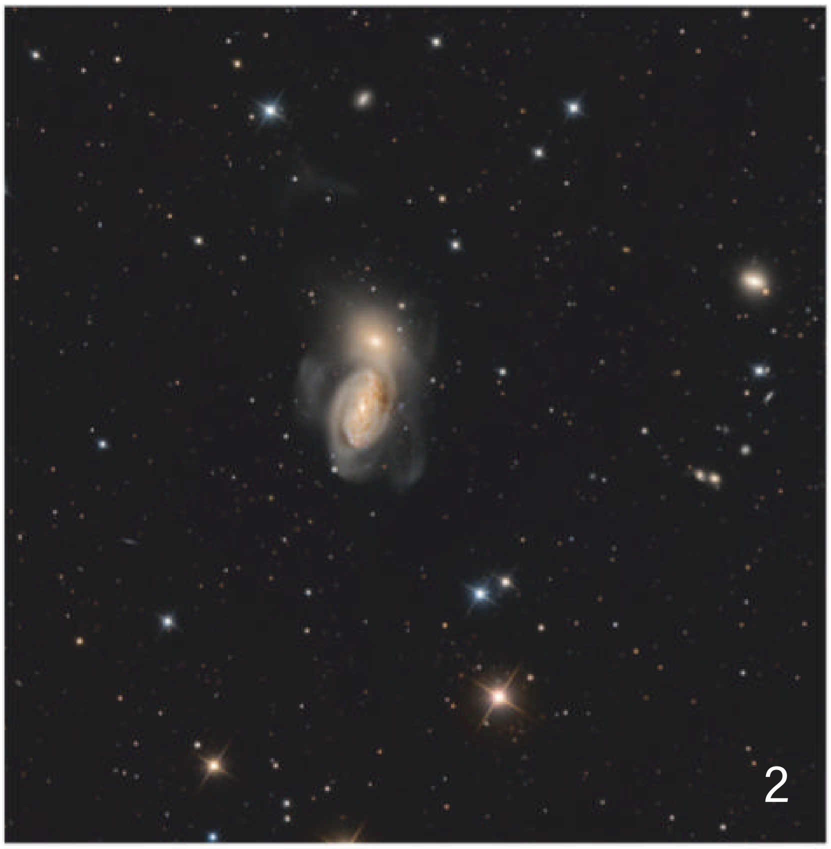
Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

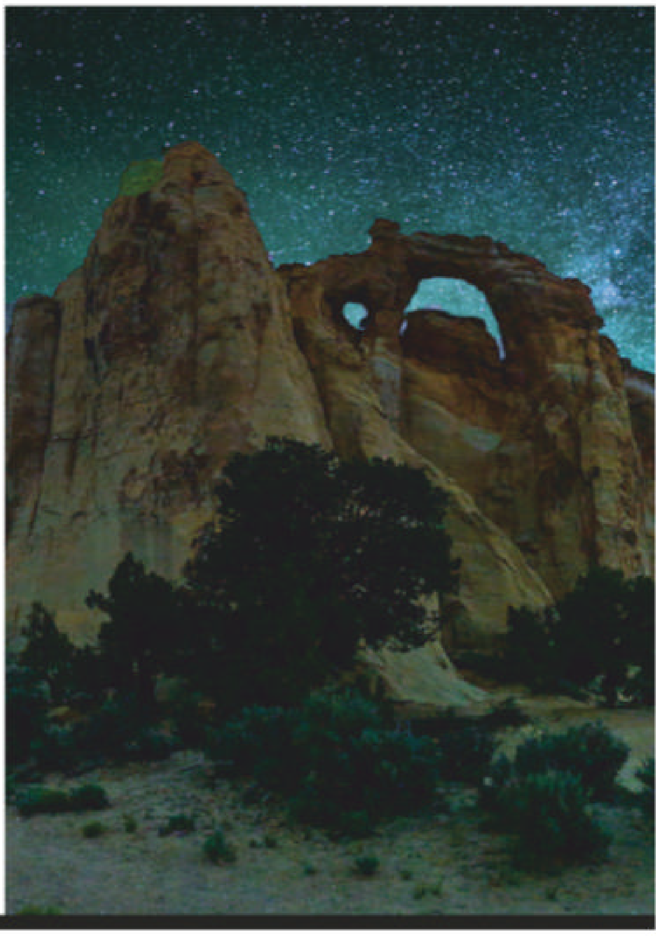
Cosmic portraits

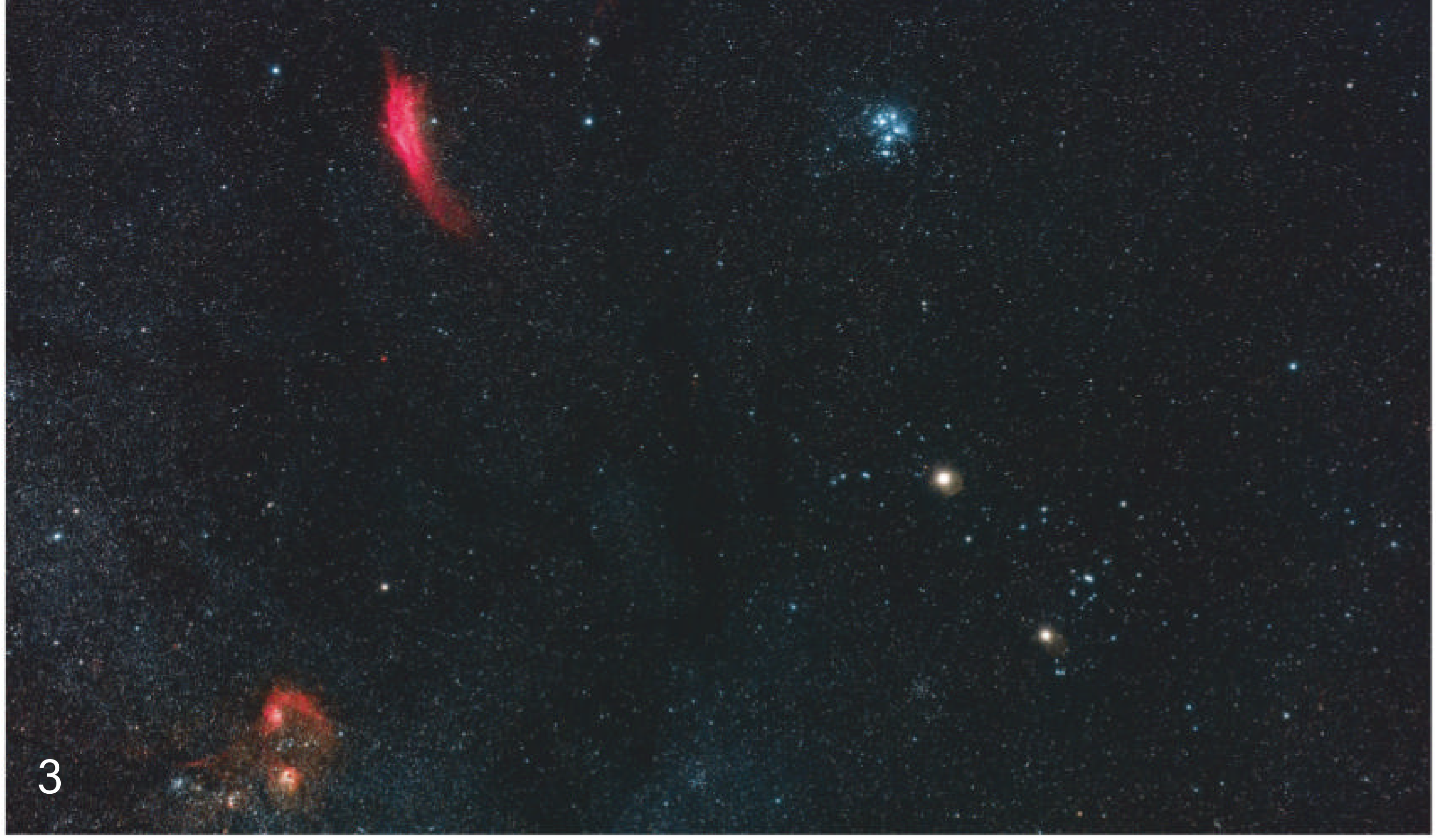


1. OVER HERE!
Often passed over in favor of the nearby North America (NGC 7000) and Pelican (IC 5070) nebulae, emission nebula Sharpless 2–119 in Cygnus is a rewarding photographic target. The imager collected nearly 23 hours of SHO data and 30 minutes of RGB data with a 2.6-inch astrograph. **▪ *Emil Andronic***

2. TWISTED HISTORY
Arp 94 comprises a pair of galaxies in Leo roughly 80 million light-years away: NGC 3226, a magnitude 11.4 elliptical, and NGC 3227, a magnitude 10.3 barred spiral. While they can be spotted through a small refractor, deep imaging — in this case, roughly 50 hours of exposure on a 16-inch scope — reveals complex tidal tails that hint at their past interactions. **▪ *Warren Keller***







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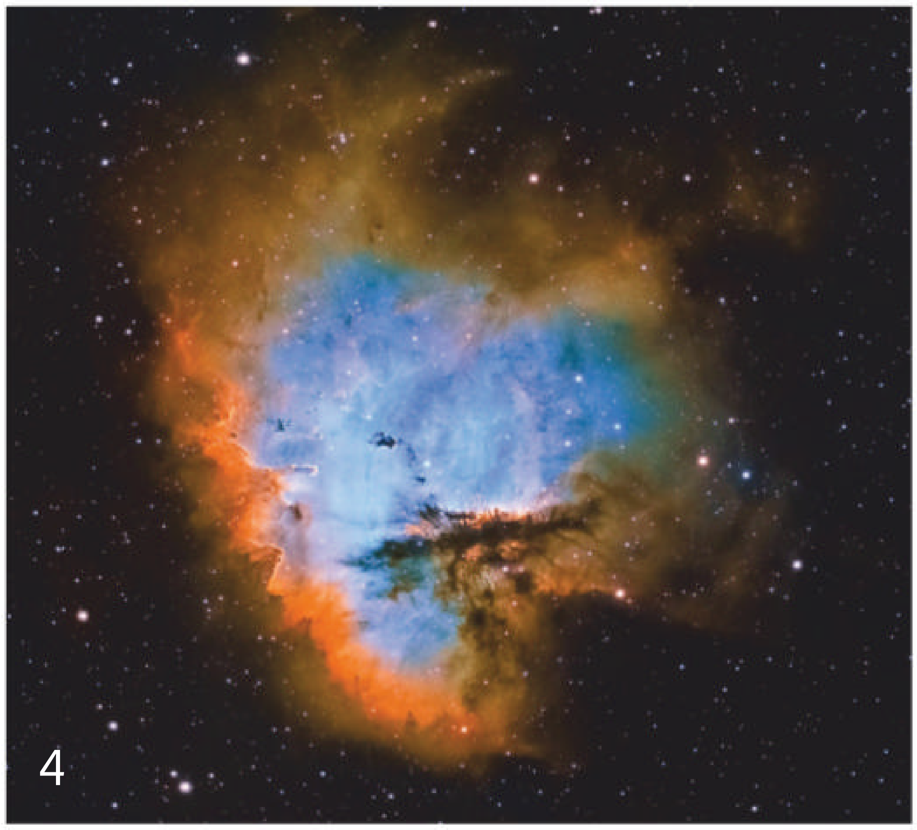

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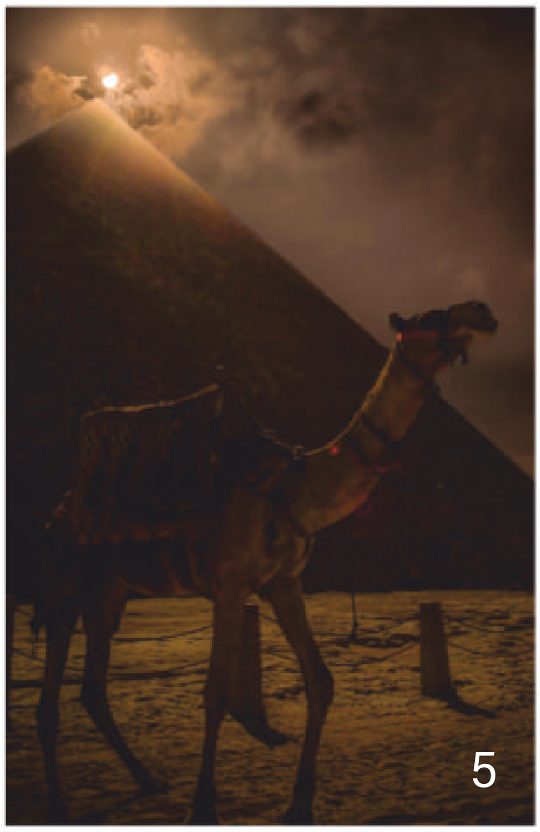

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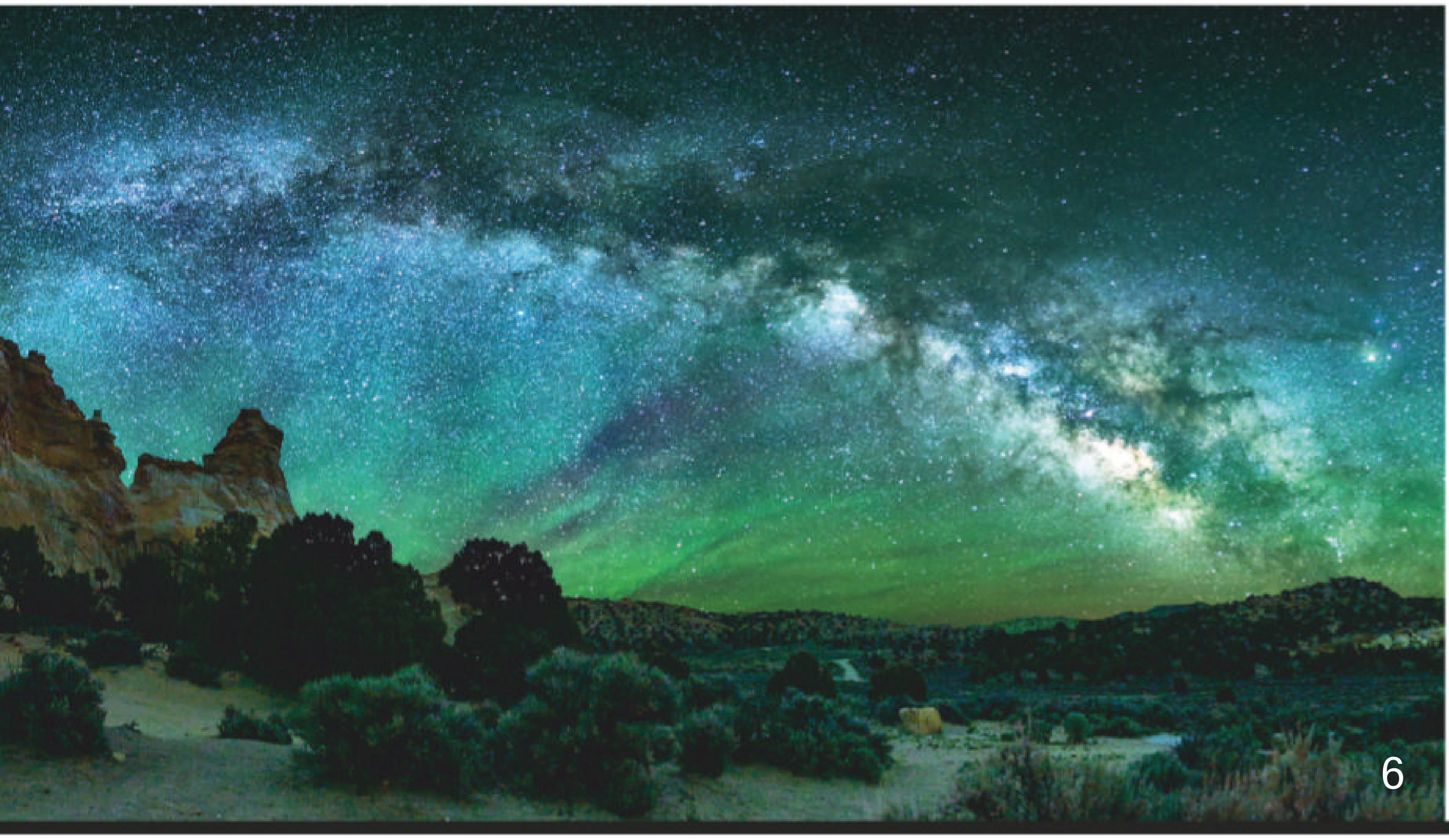


6

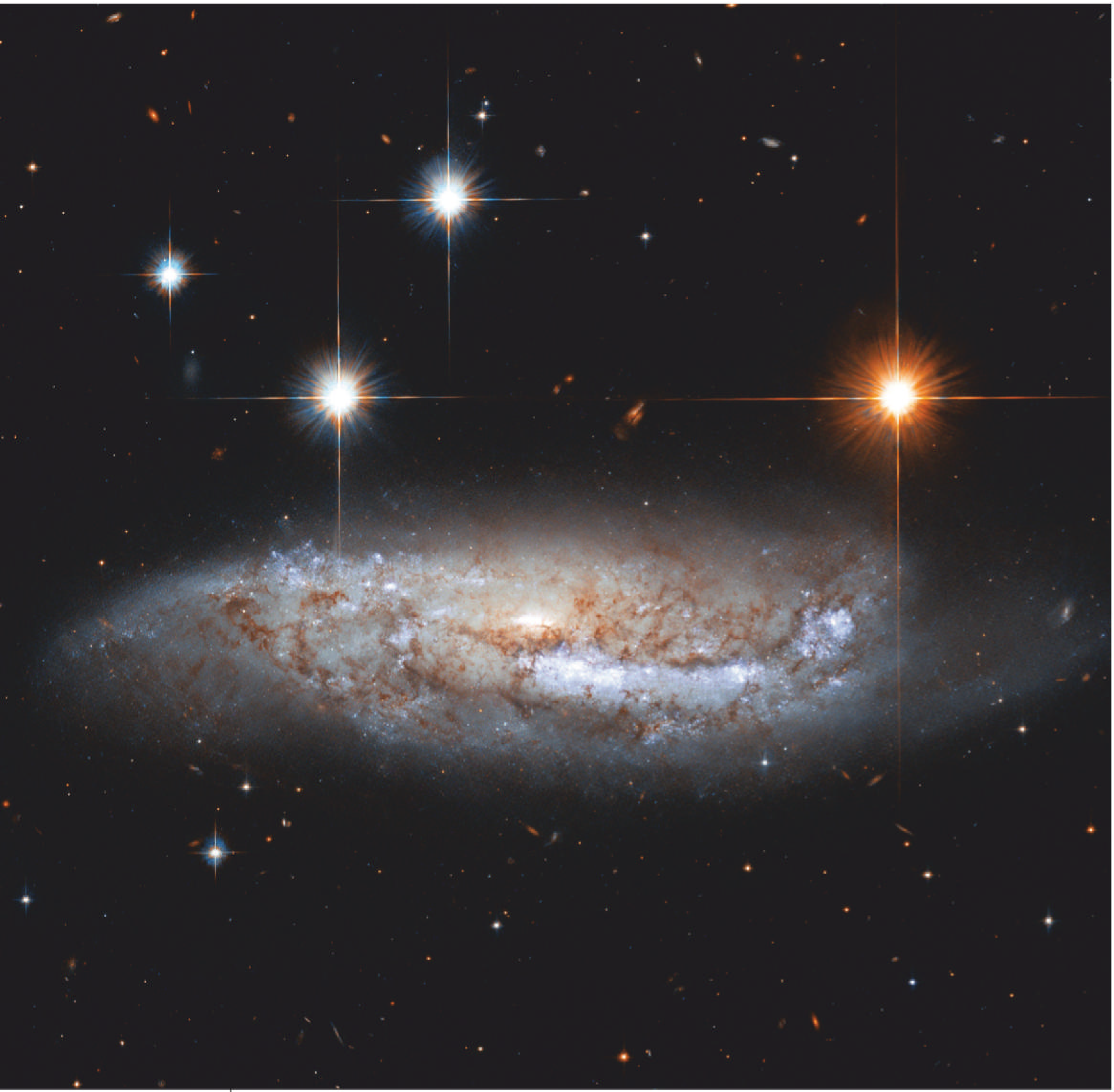
3. SEEING RED IN THE BULL
Mars reigns supreme alongside slightly dimmer but similarly hued Aldebaran (lower right) in this vista spanning Taurus, Auriga, and Perseus. Also visible are the California Nebula (NGC 1499, upper left), the Pleiades (M45, upper right), and a region of nebulosity in Auriga (lower left) that includes the Flaming Star Nebula (IC 405) and the Tadpoles Nebula (IC 410). This image was taken with a Canon EOS Ra mirrorless camera at ISO 6400, a 50mm lens at f/1.4, and about 2.1 hours of exposure. **• *Gianni Tumino***

4. WAKA-WAKA
The Pacman Nebula (NGC 281) doesn't gobble up stars in the sky but forms them instead. The intense radiation from these young stars sets the surrounding gas aglow. This image was captured over 21 hours with a 5-inch scope and processed in the Hubble palette. **• *Chuck Ayoub***

5. SIZZLING SYZYGY
The partial solar eclipse of Oct. 25, 2022, was viewable throughout most of Europe and parts of Asia and northern Africa. For this composite image from the Great Pyramid of Giza in Cairo, the photographer made use of a 10-stop neutral density filter and 1/40- and 1/800-second exposures at f/8 and ISO 160. **• *Osama Fathi***

6. GLOW IN THE DARK
Green airglow from excited oxygen atoms fills the sky over Grosvenor Arch in Utah's Grand Staircase-Escalante National Monument. This image is a composite mosaic made of 15-second sky exposures and 90-second foreground exposures. All frames were taken at f/1.4 and ISO 3200. **• *John Vermette***

SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



WORTHY OF MORE THAN A SIDEWAYS GLANCE

Sometimes, we just have to take what Mother Nature gives us. Not every galaxy tilts face-on to our line of sight, offering observers glorious views of spiral arms chock-full of brilliant blue star clusters and the reddish nebulae that give birth to them. Occasionally, we must make do with an edge-on view, which nonetheless can look stunning. Such is the case with the barred spiral galaxy NGC 3568 in the southern constellation Centaurus. While it blocks our view of the island universe's spiral structure, the dust-laden disk still appears splendid. NGC 3568 glows at magnitude 12.6 across 57 million light-years of space and is a member of the NGC 3557 group of about a dozen galaxies. ESA/HUBBLE & NASA/M. SUN

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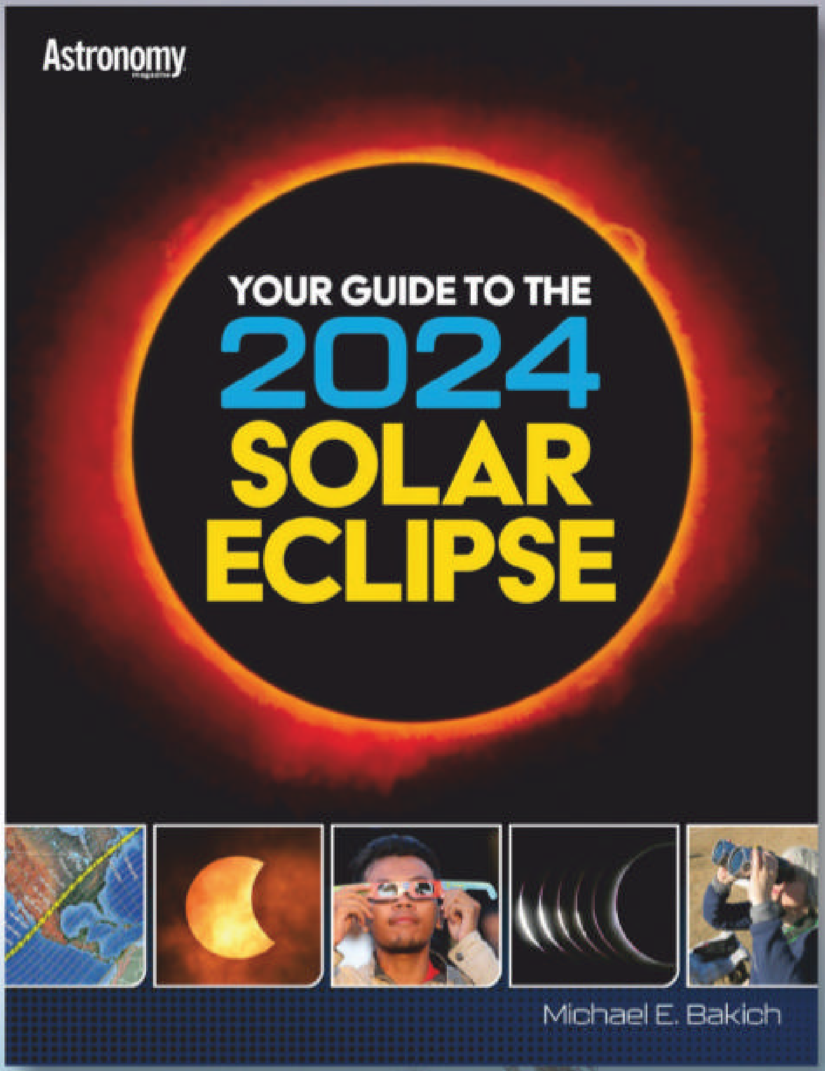
EXPERIENCE TOTALITY



Get all the information you'll need to be ready for the 2024 total solar eclipse! Expected to be the most viewed sky event in history, the April 8, 2024 eclipse is covered extensively in this must-have reference guide written by former *Astronomy* magazine editor and eclipse expert Michael E. Bakich.

In *Astronomy*'s ***Your Guide to the 2024 Solar Eclipse***, you'll learn:

- What is an eclipse, and why is this one special
- Where to go for the best view of the eclipse
- Tools to enhance your viewing experience
- Simple do-it-yourself projects to make eclipse day more fun
- And much more!

Don't miss out on this extraordinary event – get *Your Guide to the 2024 Solar Eclipse* today and start planning!

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BY MARTIN GEORGE

April 2023

Chasing the Moon's shadow

With summer now over, the nights grow noticeably longer from week to week. The earlier sunsets this month give observers great views of the two planets that orbit closest to Earth.

Venus appears first, shining brilliantly at magnitude –4.1 and by far the brightest point of light in the night sky. It hangs low in the northwest as darkness falls, crossing from Aries the Ram into Taurus the Bull at the end of April's first week. The planet passes 3° south of the Pleiades star cluster (M45) on April 10 and 11 and 8° north of 1st-magnitude Aldebaran on the 20th.

A telescope reveals a relatively bland world. During April, Venus' diameter grows from 14" to 17" while its phase wanes from 77 percent to 67 percent lit.

You can find **Mars** well to the upper right of Venus. The Red Planet spends the month drifting slowly eastward through Gemini the Twins. Glowing at magnitude 1.1, Mars appears more than 100 times fainter than Venus and is a much better match for Gemini's brightest stars, Castor and Pollux. Unfortunately, a telescope shows the Red Planet as a featureless disk spanning just 6".

Our survey of the terrestrial planets wraps up with diminutive **Mercury**, which puts on a disappointing show this month. At greatest elongation April 11, the innermost planet lies 19° east of the Sun and stands just 3° high in the west-northwest 30 minutes after sunset. Glowing at magnitude –0.1, Mercury is nearly impossible to see against the bright twilight background.

At the opposite end of the night, **Saturn** makes a fine sight in the eastern sky against the backdrop of Aquarius the Water-bearer. The ringed planet rises three hours before the Sun on April 1 and gains another two hours on our star by month's end. Glowing at magnitude 0.9, Saturn easily outshines the stars of its host constellation.

It is well worth your time to get up early and train your telescope on Saturn. The planet's oval disk measures 16" across the equator while the spectacular ring system spans 36" and tilts 9° to our line of sight. Keep an eye out for 8th-magnitude Titan, the planet's largest moon, which shows up easily through any scope. A 4-inch instrument also reveals three 10th-magnitude satellites — Tethys, Dione, and Rhea — on steady mornings.

Giant **Jupiter** reaches solar conjunction April 11 and will be hidden in our star's glare nearly all month. You might catch a brief glimpse of it in late April if you have a clear view to the east, but much better views await in May.

A rare hybrid solar eclipse takes place April 20. Observers at the ends of the path of the Moon's shadow across Earth will see an annular eclipse, when a ring of sunlight remains visible at maximum eclipse, but viewers positioned anywhere else on the center line will witness totality.

South of the equator, the best places to be lie on Australia's northwestern coast, East Timor, and Western New Guinea. The path just clips the Australian coast at Exmouth, Western Australia, where totality lasts nearly one minute centered on 3h30m UT. Greatest eclipse occurs just south of East Timor, where viewers will experience 1 minute 16 seconds of totality.

The starry sky

When I was a child, I had great fun finding my way around the night sky. Like most novices, I heard about the many signposts arrayed across the heavens. Most Southern Hemisphere observers first discover Alpha (α) and Beta (β) Centauri, which appear to point in the direction of Crux the Cross. Despite the fame of those stars, I have an even stronger memory of discovering Orion's Belt. Fortunately, both signposts appear prominent in April's early evening sky.

Orion makes a great starting point for learning the sky. To its right these April evenings lies Gemini and its two luminaries, Castor and Pollux. And directly below the Hunter resides the familiar V-shaped Hyades star cluster, which marks the head of Taurus.

The earliest recollection I have of using Orion's Belt as a guide was noting that it points toward Sirius, allowing me to quickly identify the night sky's brightest star. But I recently found myself wondering how close the extended line of the belt actually gets to Sirius.

A close examination of the belt shows that it does not run perfectly straight. I decided to test each of the three pairs formed by Mintaka (Delta [δ] Orionis), Alnilam (Epsilon [ε] Ori), and Alnitak (Zeta [ζ] Ori). It turns out that the Mintaka-Alnilam pair points most closely to Sirius — the line between them passes 1.4° to Sirius' north.

If you follow the line of the belt stars in the opposite direction, to the northwest, you soon come to Aldebaran in Taurus. Yet this projection misses the mark by even more. The closest line, formed by Mintaka and Alnilam, passes 5° south of the red giant star.

Having looked more carefully at the way Orion's Belt points, my thoughts returned to Alpha and Beta Centauri and how well they aim toward the Southern Cross. It turns out that a line joining Alpha and Beta and extended in the direction of Crux misses the main cross shape completely! The line passes 1.2° — nearly two-and-a-half times the Moon's angular diameter — north of Gacrux (Gamma [γ] Crucis), the northernmost star in the Cross.

STAR DOME

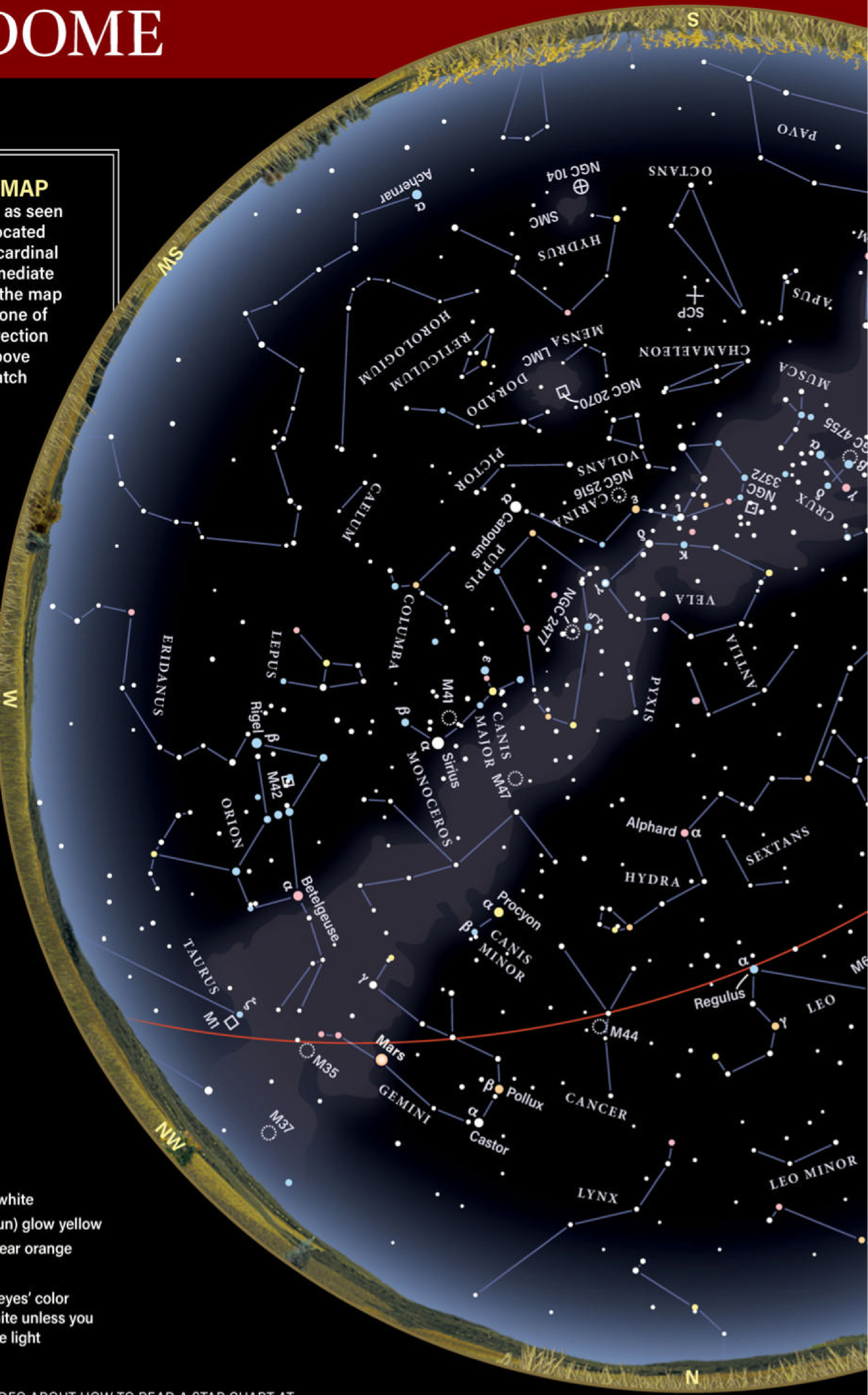
HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. April 1
8 P.M. April 15
7 P.M. April 30

Planets are shown at midmonth



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DORADO
NGC 2070
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NGC 3372
VOLANS
PICTOR
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CARINA
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CANIS MAJOR
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Sirius
Rigel
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M42
MONOCEROS
M47
ORION
Alphard
α
SEXTANS
HYDRA
α
Betelgeuse
α
Procyon
β
CANIS MINOR
TAURUS
γ
ζ
M1
α
Regulus
LEO
γ
M44
M35
Mars
β
Pollux
CANCER
GEMINI
α
Castor
M37
LYNX
LEO MINOR

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- □ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

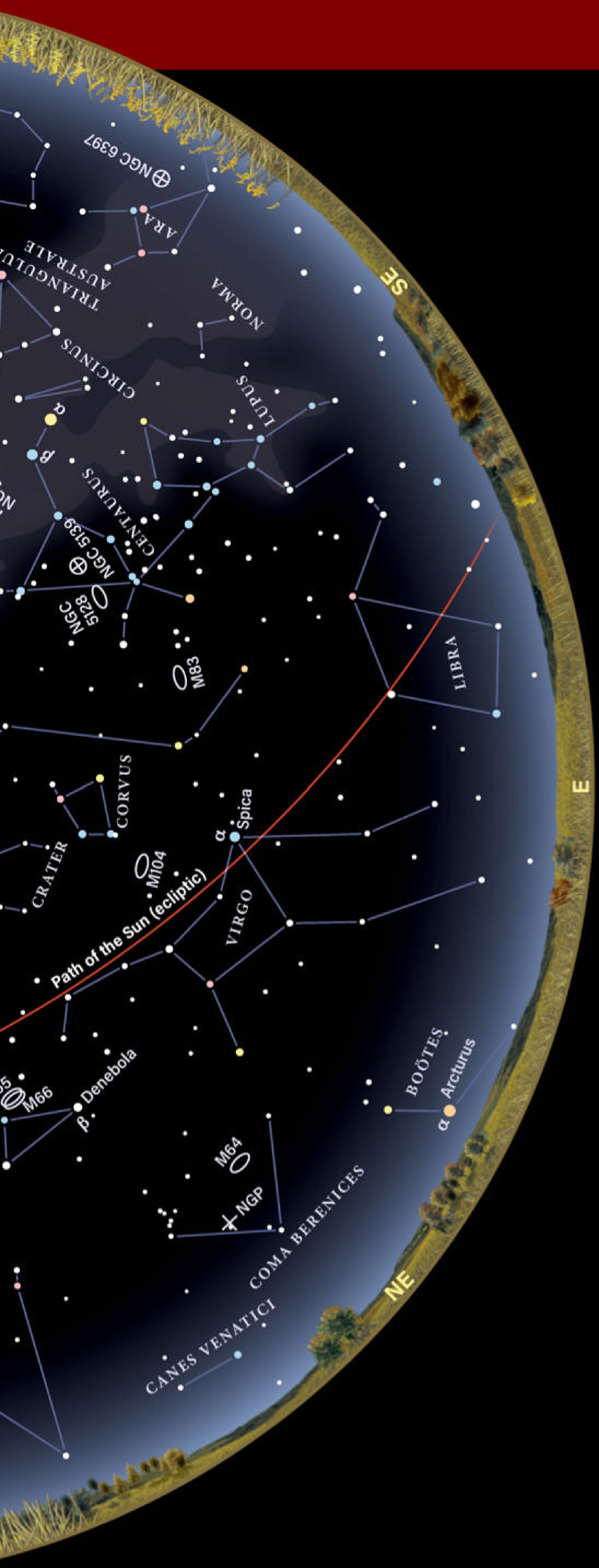
● Sirius
● 0.0 • 3.0
● 1.0 • 4.0
• 2.0 · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



NGC 6397
ARA
TRIANGULUM AUSTRALE
NORMA
SE
CIRCINUS
LUPUS
α
β
CENTAURUS
NGC 5139
NGC 5128
M83
LIBRA
CORVUS
α Spica
CRATER
M104
Path of the Sun (ecliptic)
VIRGO
E
M66
β Denebola
BOÖTES
α Arcturus
M64
NGP
COMA BERENICES
NE
CANES VENATICI

APRIL 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

6	Full Moon occurs at 4h35m UT
11	Jupiter is in conjunction with the Sun, 22h UT
	Mercury is at greatest eastern elongation (19°), 22h UT
13	Last Quarter Moon occurs at 9h11m UT
16	The Moon is at perigee (367,968 kilometers from Earth), 2h24m UT
	The Moon passes 3° south of Saturn, 4h UT
17	The Moon passes 2° south of Neptune, 17h UT
20	New Moon occurs at 4h13m UT; hybrid solar eclipse
	Venus passes 8° north of Aldebaran, 21h UT
21	The Moon passes 1.7° north of Uranus, 13h UT
	Mercury is stationary, 16h UT
23	Lyrid meteor shower peaks
	The Moon passes 1.3° north of Venus, 13h UT
24	Asteroid Vesta is in conjunction with the Sun, 9h UT
26	The Moon passes 3° north of Mars, 2h UT
27	First Quarter Moon occurs at 21h20m UT
28	The Moon is at apogee (404,299 kilometers from Earth), 6h43m UT
30	Asteroid Iris is at opposition, 16h UT

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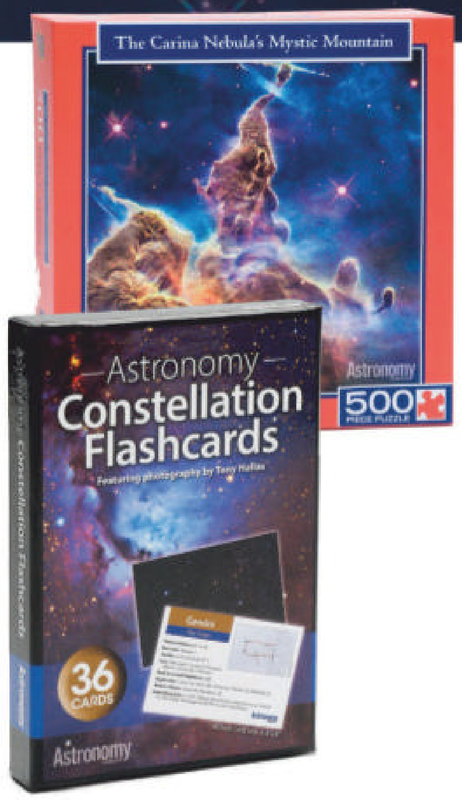
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